DISTRIBUTION AND CONCENTRATIONS OF HEAVY METALS AND MINERAL ELEMENTS IN SEDIMENTS AND EMERGENT MACROPHYTES OF SOUTH-BRAZILIAN COASTAL LAKES, WITH SPECIAL REFERENCE TO *Scirpus californicus* (C.A.Mey.) Steud. (CYPERACEAE).

DISSERTATION

zur Erlangung des akademischen Grades eines

Doktors der Philosophie

der Philosophischen Fakultät

der Universität des Saarlandes

von

MARIA ELAINE ARAUJO DE OLIVEIRA

Saarbrücken

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By

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ABSTRACT

Problems arising from contamination of aquatic systems emphasize the need for evaluation of nutrient availabilities and heavy metal concentrations in aquatic macrophytes and sediments of natural systems.

Despite the fact that many coastal lakes have been investigated in the Restinga of Rio Grande do Sul, studies involving biomass and elemental composition of emergent macrophytes in the littoral zone of south-brazilian coastal lakes are scarce.

Mineral elements and heavy metal concentrations were investigated in sediment profiles and emergent macrophytes from nine lakes (Palmital, Caieira, Peixoto, Barros, Emboaba, Rincão das Éguas, Porteira, Barros-Solidão and Tarumã lakes) along the Coastal Plain of Rio Grande do Sul, and in nine different margins of Saco de Tapes (Patos Lagoon). Besides the Cyperaceae *Scirpus californicus*, other emergent macrophytes as *Zizaniopsis bonariensis* (GRAMINEAE), *Cyperus giganteus* (CYPERACEAE), *Typha domingensis* (TYPHACEAE), and the shoreline species *Echinodorus grandiflorus* (ALISMATACEAE) were analysed.

Littoral zone of lakes represents highly differentiated biotopes and the pattern of emergent macrophytes reflects the dynamics of the littoral.

Changes in vertical profiles of phosphorus, nitrogen, calcium, magnesium and sodium have shown that mineral element concentrations in superficial sediment layers are likely to be related to several factors that reflect the dynamics of the process occurring in the water column. The interrelationships of the chemical parameters along the sediment cores and in the uppermost strata showed that naturally occurring processes differentiated the littoral zones of lakes when treated separately.

In the Coastal Plain, Caieira and Peixoto lakes showed the higher sediment phosphorus concentrations. Porteira Lake appeared with the most nutrient rich sediment in the littoral zone, except for phosphorus concentrations.

Mean nutrient concentrations in sediments of the littoral zone of lakes in the Coastal Plain are extremely low if compared to values cited for some tropical reservoirs.

In coastal systems the salinity is known to play an important role. The correlation between suspended matter and chloride concentrations demonstrates that precipitation may occur mainly in the southmost margins of the Saco de Tapes system. Furthermore, with increasing salinity, a competition between chloride ions and particulates for complexation of the dissolved metals may occur.

Heavy metal distributions in sediment cores of littoral zones in some coastal lakes reflect naturally occurring processes and, in some cases (Emboaba and Caieira lakes), weak atmospheric inputs.

Lead was the only heavy metal whose mean levels did not differ greatly between the whole sediment profiles and the upper strata in the coastal lakes.

Increase and decrease of mineral elements in aquatic environments are well monitored in tissues of *S.californicus* and other emergent macrophytes occurring in the coastal lakes. Among the mineral elements investigated, potassium was the most important and variable nutrient in plant biomass.

Although the concentrations of nutrients differed from site to site, there is an almost perfect correspondence among the mineral contents of *S.californicus* between the different lakes studied in the Coastal Plain.

Specific sources of contamination in lakes can be evaluated by different concentrations of metals in plant tissues. Among the emergent macrophytes, leaves and inflorescences showed higher heavy metal concentrations than the stems.

There are considerable differences in the heavy metal concentrations of different organs of *S.californicus* and when the element concentrations between sets of the littoral zone of different lakes is analysed statistically, the variations between organs are greater than those between individuals.

The bulrushes were not nutrient-limited, since no correlation was found between biomass and sediment nutrients. Two peak of mineral uptake was shown by the bulrushes in summer and in winter seasons, contrasting to temperate regions where summer sustains the maximum biomass and mineral elements.

S.californicus may represent a natural resource which could contribute to environmental evaluation and further lake characterization. Nevertheless, besides general criteria such as the geographical position of the lake and littoral zone location, the wind action and the type of sediment present have also to be taken into account.

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INTRODUCTION

The Restinga Biom in coastal Rio Grande do Sul (South Brazil) is characterized, besides forest belts, dunes and grasslands, by many shallow lakes. Some of them are connected with each other by small canals or to the sea, or even completely isolated. This zone, composed of lakes and swamps, corresponds to the fourth zone of the subtropical Restinga (RIZZINI, 1979; MÜLLER, 1981, 1986). The vegetation, however, are believed to have originate from surrounding areas (RAMBO, 1954), at different times (SMITH, 1962), and endemic species are not commonly referred. Appart from the flora, the Restinga Bioma exhibits some typical vertebrate species as the sand lizards of the genus *Liolaemus* (SAURIA, IGUANIDAE) (MÜLLER, 1981, 1986) and rodents of the genus *Ctenomys* (RODENTIA, CTENOMYIDAE) (TRAVI, 1981; FREITAS, 1990).

Despite the fact that many coastal lakes have been investigated limnologically (COALDRAKE, 1962; BAYLY, 1964; BAYLY et al., 1975; STONEBURNER & SMOCK, 1979; TIMMS, 1982, 1986; ESTEVES et al., 1984; SCHWARZBOLD & SCHÄFER, 1984; SCHÄFER, 1988), studies involving biomass and elemental composition of emergent macrophytes in the littoral zone of south-brazilian coastal lakes are rare.

The utilization of emergent macrophytes by man is an important part in the human history. *Cyperus papyrus* in Egypt is the most well-known case. Furthermore, *Phragmites* in Europe and Middle East is largely utilized as building material and rafts, as raw material in cellulose and fuel production (RODEWALD-RUDESCU, 1974; GRANÉLI, 1984), and for treatment of industrial wastewaters and sludge (DE MAESENEER et al., 1982; HOFMANN, 1986). The use of *Scirpus* has been known since before the discovery of America (SEIDEL, 1955) until the

present. The construction of rafts and houses by using stems of the bulrush *Schoenoplectus tatora* by inhabitants of Lake Titicaca is a marked factor on the economy of the region (COLLOT et al., 1983). Studies involving the utilization of *S.tatora* (*Scirpus tatora*) to remove metal contamination in drinking water have already been made (SALM & ARZE, 1982). In Saco de Tapes (Patos Lagoon, southern Brazil), *S.californicus* is known to be utilized as raw material for onion strings' manufacture (ARAUJO DE OLIVEIRA & NHUCH, 1986). The significant contribution of emergent aquatic plants as biomass resources are presently recognized in the United States (KRESOVICH et al., 1981).

Aquatic macrophytes may expand largely in the littoral zone of lakes, which represents highly differentiated biotopes with respect to the stability and variation of chemical and physical parameters (ULEHLOVÁ & PRIBIL, 1978). The spatial pattern of emergent macrophytes reflects the dynamic of the littoral involving thus many other factors associated with productivity and animal communities. In Brazil, studies carried out with aquatic macrophytes have been developed mainly in tropical (HOWARD-WILLIAMS & JUNK, 1977; ESTEVES, 1981, 1982; ESTEVES & BARBIERI, 1983; ROMITELLI, 1983; BARBIERI et al., 1984) and subtropical (SCHWARZBOLD, 1982; ARAUJO DE OLIVEIRA & NHUCH, 1986; NHUCH VERLANGIERI, 1989) lakes and reservoirs. Although some works in South America are dealing with biomass and energy content of aquatic plant associations (NEIFF, 1973; STEUBING et al., 1980), and morphological characteristics of the stands (TUR & ROSSI, 1976; ROSSI & TUR, 1976), studies regarding biomass, elemental composition, as well as environmental influences on monospecific stands of the bulrush *Scirpus californicus* are lacking.

In several aquatic systems, a large amount of studies have been done on plant biomass (TYLER, 1967; DYKYJOVÁ, 1973b; HUSÁK & KVET, 1973; ONDOK, 1971, 1973; ONDOK & DYKYJOVÁ, 1973; WALLENTINUS, 1973; VALIELA et al., 1975; DYKYJOVÁ & HRADECKÁ, 1976; SCHIEMER & PROSSER, 1976; STEEVER et al., 1976; BARKO & SMART, 1978; DeLAUNE et al., 1979; ESTEVES, 1979; BIRCH & COOLEY, 1982; MOOK & VAN DER TOORN, 1982; WESTLAKE, 1982; GRANÉLI et al., 1983; GRANÉLI, 1983, 1985; IHSE & GRANÉLI, 1985; SEISCHAB et al., 1985; WILE et al., 1985; ANDERSON & KALFF, 1986; BERNARD & FIALA, 1986; DICKERMAN et al., 1986; DUARTE et al., 1986; HACKNEY & DE LA CRUZ, 1986; KRISCH, 1985, 1986; ROBERTS & GANF, 1986; TATE & RIEMER, 1988) and its energy contents (WESTLAKE, 1963; BOYD, 1968, 1970a; TEAL & KANWISHER, 1970; FIALA, 1973; DE LA CRUZ & GABRIEL, 1974; DE LA CRUZ, 1975; DYKYJOVÁ & PRIBIL, 1975; DE LA CRUZ & HACKNEY, 1977; GNAIGER & BITTERLICH, 1984; DYKYJOVÁ, 1986).

Investigations on plant uptake and sediment composition (MISRA, 1938; BOYD, 1970b, c, d; BOYD & HESS, 1970; BRISTOW & WHITCOMBE, 1971; KEMP, 1971; DENNY, 1972; DYKYJOVA, 1973c; BROOME et al., 1975a, b; AUCLAIR et al., 1976; PATRICK & DeLAUNE, 1976; AUCLAIR, 1979; BURESH et al., 1980; FISH & ANDREW, 1980; BARKO, 1982; ROSICH & CULLEN, 1982; ESTEVES, 1983; JORDAN & CORRELL, 1985; SMART & BARKO, 1985; VERDOUW et al., 1985; WATSON et al., 1985; BARKO & SMART, 1986; BORNKAMM & RAGHI-ATRI, 1986; DIAB & SHILO, 1986; SASAMAL et al., 1986; BERENDSE et al., 1987), have increased in the last years.

Beside the influence of physical factors as light (SCULTHORPE, 1967; DYKYJOVÁ, 1973a; SIEGHARDT, 1973; BACKMAN & BARILOTTI, 1976; GLOSER, 1977; SHELDON & BOYLEN, 1977; PEARCY & USTIN, 1984), wave action (SCHIEMER & PROSSER, 1976; SPENCE, 1982), littoral slope (DUARTE & KALFF, 1986), depth (RICH et al., 1971; SHELDON

& BOYLEN, 1977, 1978; SINGER et al., 1983; GRACE, 1989), climatic or elevation gradients (CHAPIN, 1974; McNAUGHTON et al., 1974a; VAN DER VALK & WELLING, 1988) and between-species competition (GRACE & WETZEL, 1981; AUSTIN et al., 1985), many investigations involve tissue nutrient contents in aquatic macrophytes and in the surrounding system (LOWENHAUPT, 1956; GERLOFF & KROMBHOLZ, 1966; BJÖRK, 1967; GOULDER & BOATMAN, 1971; POLISINI & BOYD, 1972; DYKYJOVÁ, 1973b, c; JONES, 1974; BROOME et al., 1975b; GALLAGHER, 1975; KVET, 1975; MASON & BRYANT, 1975; PATRICK & DeLAUNE, 1976; GAUDET, 1975, 1977; HOWARD-WILLIAMS & HOWARD-WILLIAMS, 1978; CARPENTER, 1980; CONGDON & McCOMB, 1980; ESTEVES, 1980; RAGHI-ATRI & BORNKAMM, 1979, 1980; ROGERS & BREEN, 1980; SMART & BARKO, 1979, 1980; VAN DER LINDEN, 1980; LANDERS, 1982; SMITH et al., 1982; DYKYJOVÁ & KVET, 1983; HUEBERT & GORHAM, 1983; SHAVER & MELILLO, 1984; BORNKAMM & RAGHI-ATRI, 1986; SOLSKI, 1986), especially phosphates (CAINES, 1965; GOLTERMAN et al., 1969; CHAPIN, 1974; HAUMANN & WAITE, 1978; CARIGNAN & KALLF, 1979; GOLACHOWSKA, 1979; GOLTERMAN, 1973, 1980; BARKO & SMART, 1980, 1981; CARY & WEERTS, 1983) and their availabilities (CLESCERI & LEE, 1965; RIGLER, 1966; LEE, 1973; LEAN & RIGLER, 1974; STEWART & MARKELLO, 1974; LEAN, 1973a, b, 1976; KUFEL, 1977; PETERS, 1977; LEAN & NALEWAJKO, 1976, 1979; CHAPRA, 1982; GUNATILAKA et al., 1983; LEAN et al., 1983; FOX et al., 1985; CURRIE et al., 1986; FLEISCHER, 1986; FÖRSTNER et al., 1986; FOY, 1986; KLAPWIJK & BRUNING, 1986; LEAN et al., 1986; McQUEEN et al., 1986; PETTERSSON & BOSTRÖM, 1986; ARMENGOL & VIDAL, 1988; GOLTERMAN, 1988; GUNATILAKA, 1978, 1983, 1988; GUNATILAKA et al., 1988).

The increase and decrease of element concentrations in lake water reflects directly the interactions among macrophytes, sediment and water. The concentration of an element in macrophyte tissues reflects the availability

of the element in the environment. Moreover, "foreign" substances in the lake are readily documented since sediment act as a "sink" and emergent macrophytes as a "permanent witness".

In the hydrological cycle, sediments are very important regarding 'heavy' metal transport and accumulation. By this manner, the quality of the surrounding system as well as its evolution are documented. Effects and concentrations of heavy metals in aquatic environments are well monitored if only one plant species within different areas is used (FÖRSTNER & WITTMANN, 1981), since heavy metal concentrations in tissue plants can vary greatly between different sites.

Heavy metals in aquatic systems can be originating from geologic weathering, industrial processes, leaching from garbage and solid waste, rural areas, animal excretions and domestic effluents (FÖRSTNER & WITTMANN, 1981), and the greater part of them is rapidly adsorbed onto particulate material. The role of heavy metals in aquatic systems has been reviewed by many authors (OLIVER, 1973; SANCHEZ & LEE, 1973; McNAUGHTON et al., 1974b; KARBE et al., 1975; LEE, 1975; MATHIS & KEVERN, 1975; CLINE & CHAMBERS, 1977; ENK & MATHIS, 1977; MAYES & McINTOSH, 1977; MacLEAN, 1979; CUSHING,Jr. & THOMAS, 1980; WELSH & DENNY, 1980; ESTEVES et al., 1981; FÖRSTNER, 1976, 1977, 1982; LEE et al., 1982; O'KEEFFE & HARDY, 1984; HARDY & O'KEEFFE, 1985; AHLF et al., 1986; EL GHOBARY & LATOUCHE, 1986; EVANS et al., 1986; MUNAWAR et al., 1986; STILLER & IMBODEN, 1986; LANDNER, 1987; FREVERT & SOLLMANN, 1987; DUNBABIN, 1988). In contrast to lead and cadmium, the essential metals such as copper and zinc have important biochemical functions in the organism. For this reason, essential metal concentrations are generally higher in the organism than in water. However, if the homeostatic control mechanisms cease to function and the essential metal concentration is too

high, the metal can reach acute and/or chronic toxic levels. Nevertheless, an increasing heavy metal concentration in the environments does not mean an elevated concentration in organisms (FÖRSTNER & WITTMANN, 1981).

OBJECTIVES

Problems arising from contamination of aquatic systems have emphasized the need for studies through which the availability of nutrients and heavy metal concentrations in aquatic macrophytes and in sediments of natural systems can be evaluated.

In Brazil, studies dealing with nutrient uptake by aquatic macrophytes are almost new (HOWARD-WILLIAMS & JUNK, 1977; ESTEVES, 1981, 1982; ESTEVES & BARBIERI, 1983; BARBIERI et al., 1984). In Rio Grande do Sul some authors have applied efforts in classifying lakes, mainly with reference to their chemical composition and location along the Coastal Plain (DELANEY, 1960; SCHWARZBOLD & SCHÄFER, 1984; SCHÄFER, 1988). Except for a few contributions on occurrence and distribution of macrophytes in lakes (SCHWARZBOLD, 1982) and in swampy areas (IRGANG et al.,1984), special studies involving nutrient dynamic and contribution of nutrient and biomass in the system are almost rare in this region (ARAUJO DE OLIVEIRA & NHUCH, 1986).

Emergent macrophytes such as *Scirpus californicus* in subtropical regions appear to have a continuous growth and, consequently, are more productive than its temperate-climate counterparts. Nevertheless, studies dealing with utilization of emergent macrophyte biomass

as alternative energy sources are not well-developed in Brazil.

S.californicus normally occupies large areas in the littoral zone of southern Brazil coastal lakes and, in most of the cases, establishes extensive monospecific stands. Tissue analysis seems particularly usefull for evaluation of nutrient concentrations and heavy metal accumulations in bulrushes growing in the littoral zone of coastal lakes. Beside the seasons, the location of the littoral zone, wind exposure and human activity are important factors to be considered when dealing with nutrient dynamics.

Moreover, the significance of sediments in the evaluation of environmental conditions are indisputable, since metal contamination and natural or human influences can be well delineated in a sediment gradient within the littoral zone of lakes. Physical heterogeneity of the margin, however, associated with wave action and material deposition are also factors that affect sediment type in the littoral zone.

This research attempted to study the seasonal variations in tissue nutrients and heavy metal contents in the Cyperaceae *S.californicus*, as well as in sediment profiles in the littoral zone of coastal lakes. Besides sites variations within different margins in Saco de Tapes (Patos Lagoon), mineral element and heavy metal content comparisons within other emergent macrophytes such as *Zizaniopsis bonariensis* (Bal.& Poitr.) Speg. (GRAMINEAE), *Cyperus giganteus* Vahl (CYPERACEAE), *Typha domingensis* Pers. (TYPHACEAE), and the shoreline species *Echinodorus grandiflorus* (Cham. & Schl.) Mich. (ALISMATACEAE), also formed an aspect of the assessment.

STUDY AREA

Evolution of the Coastal Plain

The Coastal Plain of Rio Grande do Sul, Brazil, and north Uruguay is characterized by a large lowland area, numerous lakes, coastwise terraces, and dunes (DELANEY, 1966). This region, called Coastal Province by VILLWOCK (1972), comprises two large distinct geological units: the Basement and the Pelotas Basin (VILLWOCK, 1984, VILLWOCK et al., 1986) (Fig. 1). The sedimentary sequence accumulated in the Pelotas Basin is settled on older rocks which is formed by the Sul-Rio-grandense and Uruguayan Shield and, in the northern of the parallel 30°, by the sedimentary and volcanic sequences of the Paraná Basin (VILLWOCK, 1984; VILLWOCK et al., 1986).

In Rio Grande do Sul, the Paraná Basin sedimentation has begonnen during Middle Permian, with periglacial deposits. The continental phase extended into the Mesozoic and provided the accumulation of sandstones (Rosário do Sul Formation) deposited in a fluvial and associated lake environments (VILLWOCK, 1984). The Botucatu Formation accumulated in a "desert environment" over which the lavas of Serra Geral Formation flowed (Upper Jurassic - Lower Cretaceous). (VILLWOCK, 1984).

The Pelotas Basin is related to geotectonic events that led to the opening of the South Atlantic Ocean from the Jurassic Period onwards, which resulted in the rupture of the Gondwana continental block and subsequent separation of the African and South American continents (VILLWOCK, 1984; VILLWOCK et al., 1986).

The Coastal Plain, included in the Pelotas Basin, is an extensive (640 km long) and large area whose elevations, in the Restinga of Rio Grande do Sul, do not

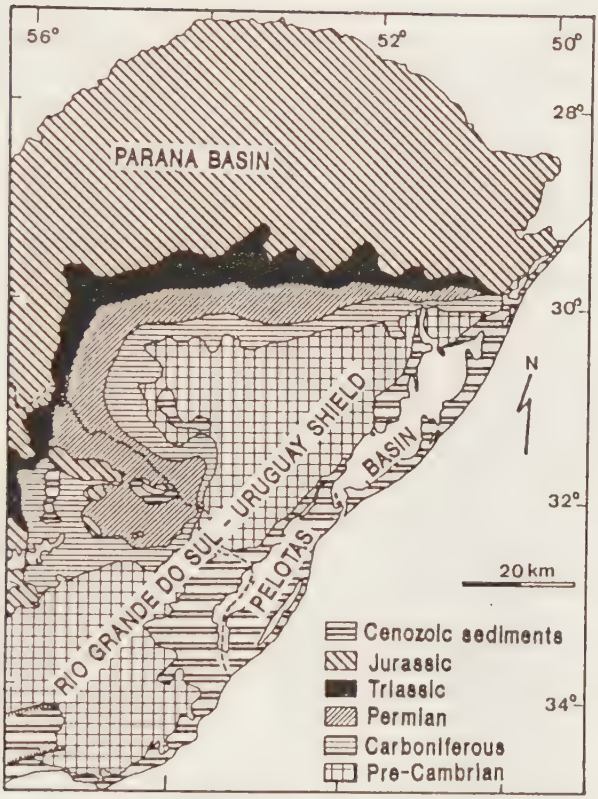


Figure 1: The Pelotas Basin and its relationships with other geotectonic units in southern Brazil and Uruguay (after DELANEY, 1966, modified).

exceed 6 meters, except for some dunes (WAECHTER, 1985). It is included between the latitude 29°12' and 33°48'S, and longitude 49°40' and 53°30'W (SCHWARZBOLD & SCHÄFER, 1984) and consists of a set of sedimentary facies, discontinuous in space and time, resulting from the displacement of sedimentation environments over the region (VILLWOCK, 1984). Regarding geormophologic

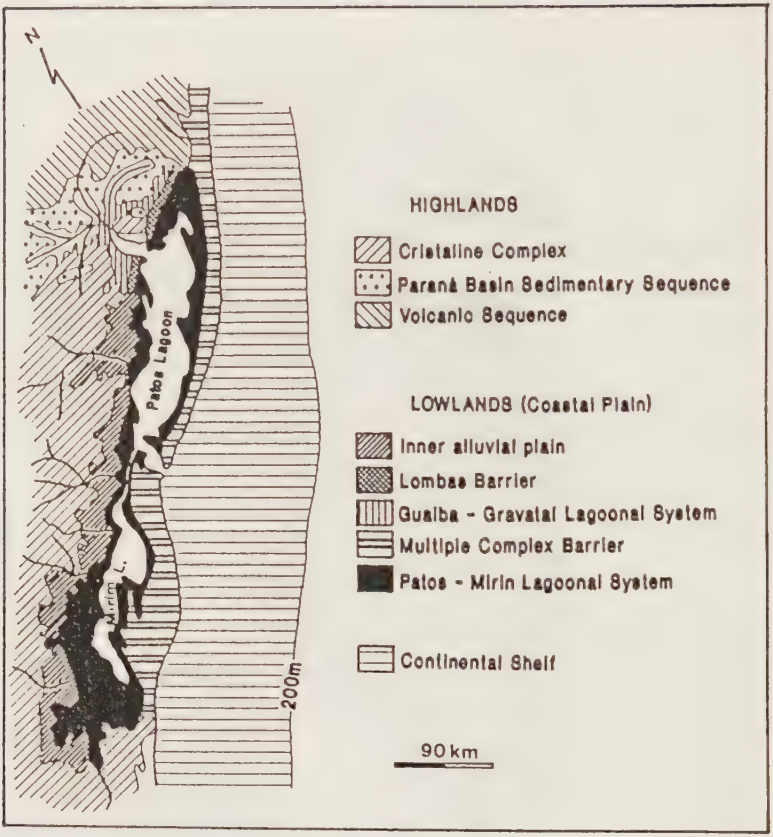


Figure 2: Geomorphologic compartmentation of the Coastal Plain (after VILLWOCK, 1984, modified).

compartmentation, the Coastal Plain is formed by (Fig. 2):

a) the Inner Alluvial Plain, firstly called Lagoonal Plain by DELANEY (1965), comprises a lowland plain between the Sul-Rio-grandense Shield and the Patos-Mirim Lagoonal System;

b) the Lombas Barrier, a long northeast-southwest strip originated by aeolic sandy deposits and distributed in groups of rounded hills. First characterized by DELANEY (1965) this system is related to an ancient line of sea cliffs controlled by a fault line developed along the Pre-Cambrian and partly buried by aeolian deposits (VILLWOCK, 1972);
c) the Guaíba-Gravataí Lagoonal System, isolated by the Lombas Barrier, formed two lagunary bodies (VILLWOCK, 1984): the Chico Lomã Swamp and the Porto Alegre Basin;
d) the Multiple Complex Barrier, a sucession of fairly even crests and elongated depressions, expanded from North, between the Plateau hillside and the Atlantic Ocean, to South in a strip that isolated the Patos-Mirim Lagoonal System;
e) the Patos-Mirim Lagoonal System, occupies the first and largest depression of the Multiple Complex Barrier. The Barros Lake, the Patos and Mirim lagoons, as well as the São Gonçalo Alluvial Plain, take part in it;
f) the Continental Shelf, which forms the same geological unit with the emerged plain.

Stratigraphically, the Coastal Plain is formed from various units, some of which are lithostratigraphic and others chronostratigraphic (VILLWOCK, 1984). The Gravataí Formation consists in slide deposits formed by fragments coming from predominantly sedimentary and volcanic geologic units, surrounded by a clayey and clayey-silty matrix. The Serra de Tapes Laterite was firstly described by DELANEY (1965) and consists of sandy-siltic-clayey deposits, exposed along a boundary fringe between the Sul-Rio-grandense Shield and the Coastal Plain. Both formations differed with respect to the various source areas and to the relief energy. Nevertheless, both developed at the inner limit of the Coastal Plain, coming from the bordering highlands (VILLWOCK, 1984). The

deposition occurred from the Miocene to the Pleistocene-Holocene, when alternative humid and arid climates followed the glacial cycles of the North Hemisphere (VILLWOCK, 1984). The Graxaim Formation occurs along the western border of the Coastal Plain, and consists of conglomeratic and sandy-silty facies, which covers the marine sediments of the great Miocene transgression, and is covered by the Chuí Formation deposits of the Pleistocene (VILLWOCK, 1984). The Chuí Formation is composed by little silt and clay, accumulated as beach and shallow marine environments (DELANEY, 1965). Further division of this unit (SOLIANI, 1973; JOST & SOLIANI, 1976) included the Taim Member (shallow marine unit) and the Santa Vitória Member (lagoonal facies). Guaíba Formation constitutes accumulation of sediments along submerged river valleys during marine transgressions (VILLWOCK, 1984). Itapoã Formation includes medium to fine quartz sands, with ferruginous cement (VILLWOCK, 1984). It is synchronic with the Chuí Formation and constitutes sucession of regressive dunes of the Pleistocene. Quinta Formation is included in the Holocene of the Coastal Plain (DELANEY,1965) and more generically is referred to as a group of deposits which croped out in the littoral strip and accumulated after the gratest Holocene transgression (GODOLPHIM, 1976).

The sedimentation processes and morphology of the region were controlled by the succession of transgressive and regressive marine events (VILLWOCK, 1984). This author delineated a tentative paleogeographic configuration of processes which occurred in the Coastal Plain, and SCHWARZBOLD & SCHÄFER (1984) established their relationship to the origin of coastal lakes:

a) during Pliocene regression a large area was covered with coarse clastic deposits which constituted part of the Graxaim Formation;

b) after the first Pleistocene transgression-regression cycles, the Guaíba-Gravataí Lagoon System was isolated by the Lombas Barrier;
c) in the Middle Pleistocene, the isolation of the Patos-Mirim Lagoon System begun with the formation of the Multiple Barrier;
d) in the Upper Pleistocene (after the third transgression-regression cycle) a second barrier was added to the Multiple Barrier, and later the alluviation of the Patos-Mirim Lagoon System, an extensive coastal plain was formed until the present 100 meter isobath;
e) during the high Holocene transgression, occurred the formation of a sea cliff at the Multiple Barrier and the abrasion of the Holocene lagoon terrace in the Patos-Mirim System;
f) after the Holocene regression a third barrier was added to the Multiple Barrier, forming Mangueira Lake in the southern and the necklace lakes in the northern part of the Coastal Plain. During this regression emerged the Holocene terrace which constituted the São Gonçalo alluvial plain and a greater part of the spits on the banks of Patos and Mirim lagoons.

Palaeoclimatic Conditions

Studies on vegetation succession during the Late Quaternary in the coast of Rio Grande do Sul were developed by using spores and pollen of terrestrial and aquatic plants (LORSCHEITTER & ROMERO, 1985). The results show evidence of a large influence of grasslands along the Coastal Plain during the last Pleistocene glacial stage, with cold climate and high humidity. Moreover, the presence of *Notophagus* pollen in the samples is taken as an indicator of southwestern winds during that stage, which were stronger in phases of more intense colder

climate.

A great predominance of Cyperaceae pollen, followed by Gramineae, is likely to be related to the marshy environmental expansion on the Coastal Plain during the Early Würm. This event seems to be characterized by a cold and humid climate, where development of swamps and lakes was pronounced but plant diversity was scarce (LORSCHEITTER & ROMERO, 1985).

Cyperaceae and Pteridophyta, at the end of the Interstadial Würm (approximately 42,000 yr B.P.) showed a pronounced reduction, probably due to drier soil and temperature lowering (LORSCHEITTER & ROMERO, 1985). Furthermore, *Notophagus* pollen indicates that southwestern winds were intensive during this event. The great plant diversity, however, suggests generally wet and diversified soils.

During the Late Würm three different environmental conditions were observed (LORSCHEITTER & ROMERO, 1985):

a) a humid environment characterized by a decrease in Cyperaceae and increase in Gramineae species and, consequently, decrease of swampy soils. Cold climate and erosive processes were intense.

b) a short dry environment, with decrease of swamps and low soil humidity. The dryness of the environment was also confirmed by the increase of grasslands species. The rise of *Notophagus* pollen indicates that winds coming from the southwest were more intense than during any other phase of the glacial Würm.

c) a humid environment corresponding to the end of the Pleistocene. The enhancement of Cyperaceae and Gramineae indicated an increase of humidity similar to those conditions at the beginning of the Late Würm.

The Holocene was characterized by an alteration in the flora, which suggests higher temperature and humid conditions. The beginning of the Holocene Transgression is coincident with a significant reduction of Gramineae (LORSCHEITTER & ROMERO, 1985).

Climate

The climate in the Coastal Plain of Rio Grande do Sul is included in the "Cfa" type (humid subtropical) according to the Köppen System (MOTA, 1951).

From spring to summer, the southern position (28°S) of the Santa Helena anticyclone (subtropical semipermanent South Atlantic anticyclone) has an influence on the plain (EIDT, 1968), and convective rainfall predominates (HASENACK et al., 1987). From autumn to winter, the Santa Helena anticyclone is shifted northward (to Tropic of Capricorn) and the polar cyclones, followed by polar migratory anticyclones, promote frontal rainfall and lower temperatures (HASENACK et al., 1987).

The circulation of air over the Coastal Plain is dominated by winds from the edges of the semipermanent South Atlantic anticyclone (EIDT, 1968). Winds from the northeast and east are frequent all over the year, but occasionally W, S and SE winds occur when cold air masses from the South reach the region (PUHL, 1961; ALVAREZ et al., 1981).

The annual mean temperature is about 17.5°C, with maximum mean of 22.9°C and minimum of 12.9°C (ALVAREZ et al., 1981). The climatic winter occurs for four months, but june and july are the coldest ones (NIMER, 1979). The average annual rainfall in the region is about 1,300 mm, but the littoral plain lies between the isohyets of 1,300 and 1,200 mm (BEIRSDORF & MOTA, 1973). In northern Coastal Plain HASENACK et al. (1987) have found an annual mean temperature of about 20°C, and average annual rainfall between 1,504 and 1,323 mm (Fig. 3).

In the Tapes region (5 m a.s.l.) the annual mean temperature reaches 18.8°C, with maxima of 39.7°C and minima of -2.2°C (Fig. 3) The average annual rainfall is about 1,225 mm, and very humid periods occur from june to september (GUERRA, 1988).

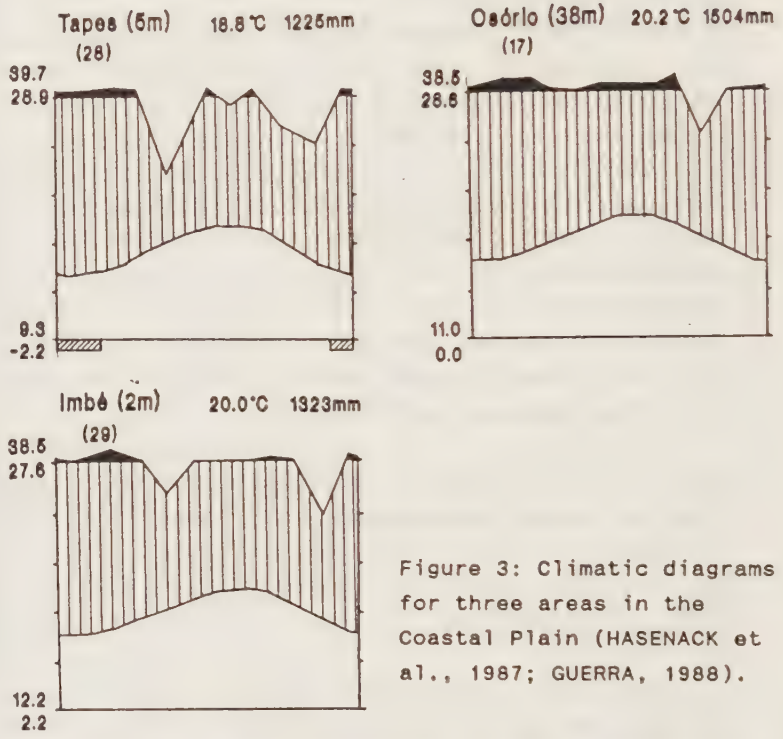


Figure 3: Climatic diagrams for three areas in the Coastal Plain (HASENACK et al., 1987; GUERRA, 1988).

Investigated Lakes

All nine investigated lakes are located on the Coastal Plain. Except for Barros Lake, whose formation is related to Pleistocene events (ARAUJO DE OLIVEIRA, 1983; 1990a), all other lakes are situated on the Holocene terrace. They are relatively shallow (Table 1) and their geographical positions are indicated in Fig. 4 and 4.A.

The water transparency in most of the lakes is largely a function of the phytoplankton, while suspended materials are responsible for the rapidly light extinction in others (ARAUJO DE OLIVEIRA, 1983, 1990a).

Table 1: Location and morphometric parameters of some coastal lakes.

Lake	latitude S	longitude W	superface (km^2)	maximum depth (m)
1. Palmital	29°49'	50°09'	11.7	3.0
2. Caieira	29°51'	50°08'	2.5	2.0
3. Peixoto	29°52'	50°14'	3.3	2.5
4. Barros	29°55'	50°23'	84.3	4.3
5. Emboaba	29°58'	50°13'	1.3	1.7
6. Rincão das Éguas	30°18'	50°18'	5.5	3.5
7. Porteira	30°22'	50°20'	18.7	4.2
8. Barros-Solidão	30°31'	50°24'	7.6	7.5
9. Tarumã	30°45'	50°34'	4.2	6.0

The Patos Lagoon is the greatest lagoonal system of South America (11,000 km^2), with 250 km long and 60 km broad (HERZ, 1974). Its margins show a succession of extensive bays and sand ridges resulting from wind-generated waves and littoral currents (VILLWOCK, 1972). The aquatic system of Saco de Tapes (30°40'S and 51°20'W) (189 km^2) results from a sand ridge formation (of about 21 km long), during the Holocene regression, in the occidental part of Patos Lagoon (Fig. 4.B). In that system, the nine margins sampled included: 1. south

margin; 2. here referred as "south-bay" (Photo 1); 3. the spit of the sand ridge, here referred as "esporão"; 4. southeast margin (Capão da Lancha) (Photo 2); 5. east margin (Photo 3); 6. northeast margin (near Adauto Stream); 7. north margin; 8. west margin (near the town of Tapes); and 9. west margin (Capão da Moça Farm).

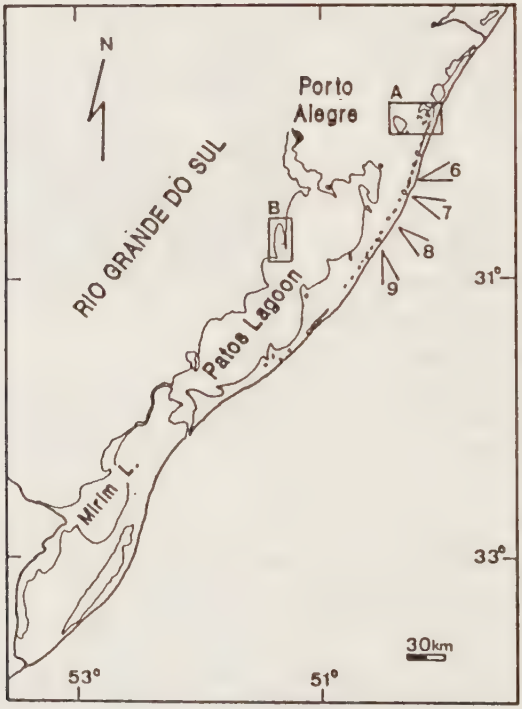


Figure 4: Location map. A: lakes in the northern region of the Coastal Plain; B: Saco de Tapes. Numbers refer to lakes mentioned in Table 1.

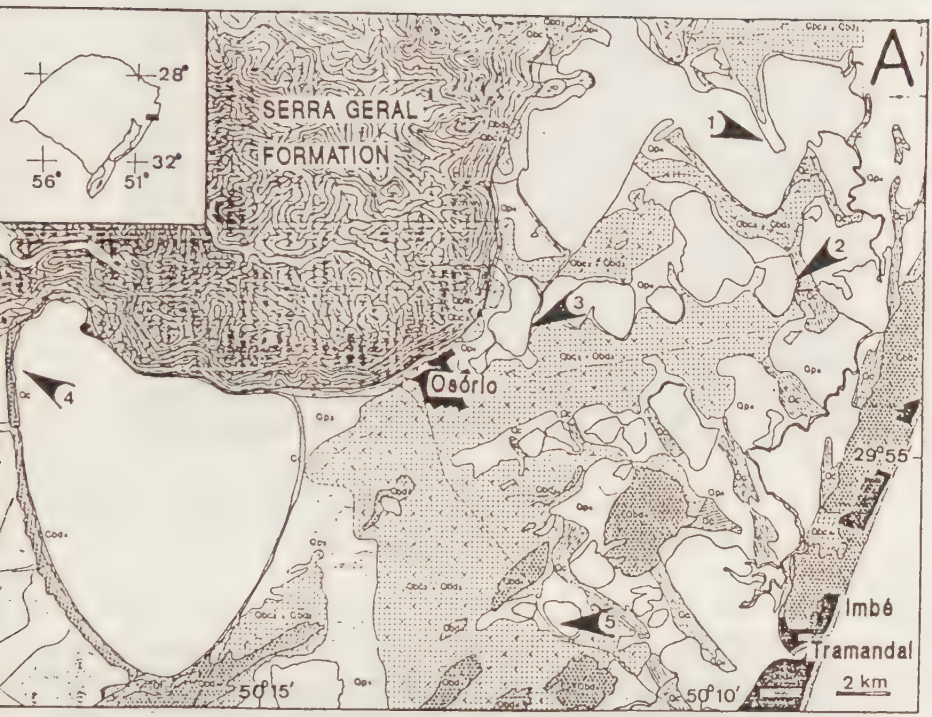


Figure 4.A: Sampled margins in coastal lakes of the northern portion of the plain. Numbers refer to lakes mentioned in Table 1. Acronyms refer to Quaternary deposits (CECO, 1984) Qc=lagoonal shore crests, Qp3 and Qp4=lagoonal; Qbc4=marine; Qbd4=aeolian and dunes; Qbd2, Qbc2, Qbc3 and Qbd3=intertidal, partially recovered by aeolian.

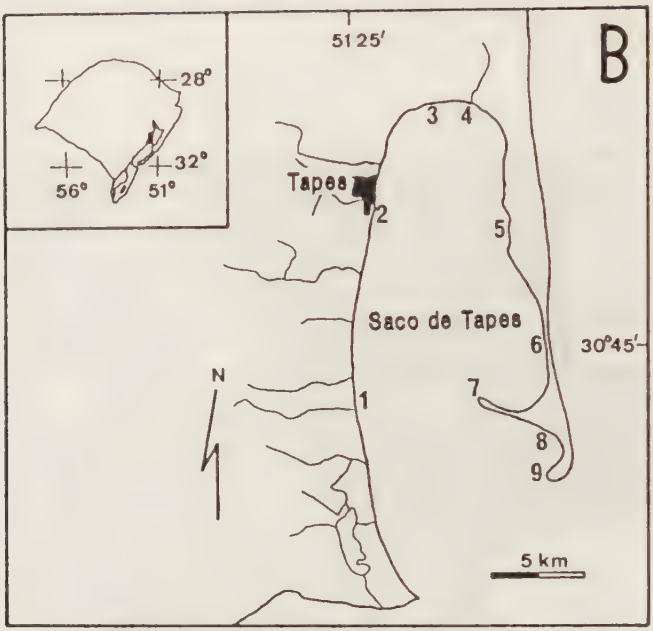


Figure 4.B. Sampled margins in Saco de Tapes (Patos Lagoon). Numbers are referred in the text.

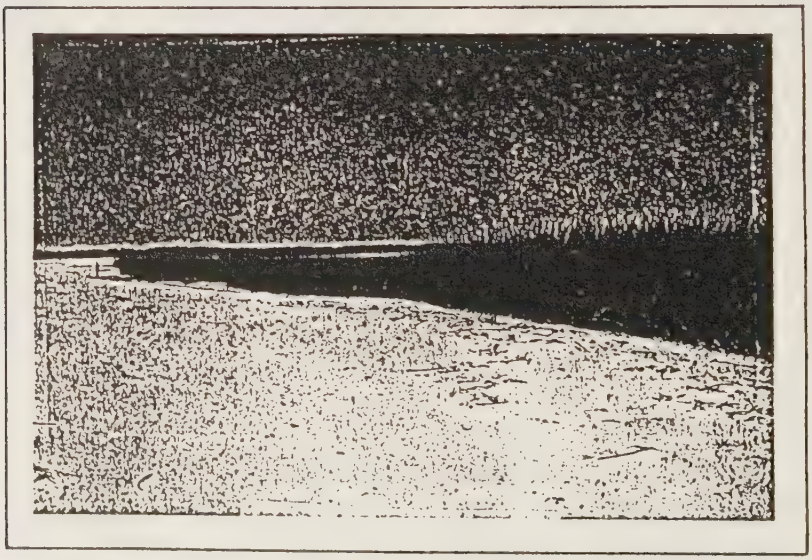


Photo 1: South-bay (Fig. 4.B.8), between the south edge and the "esporão". Aspects of *S.californicus* stands and shoreline.

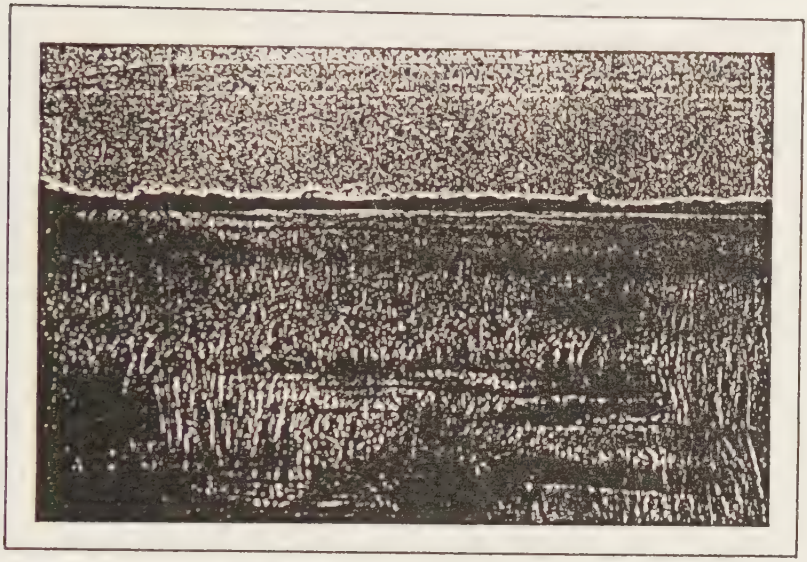


Photo 2: Southeast margin (Capão da Lancha, Fig. 4.B.6). Aspects of overflowed shore and *S.californicus* stands.

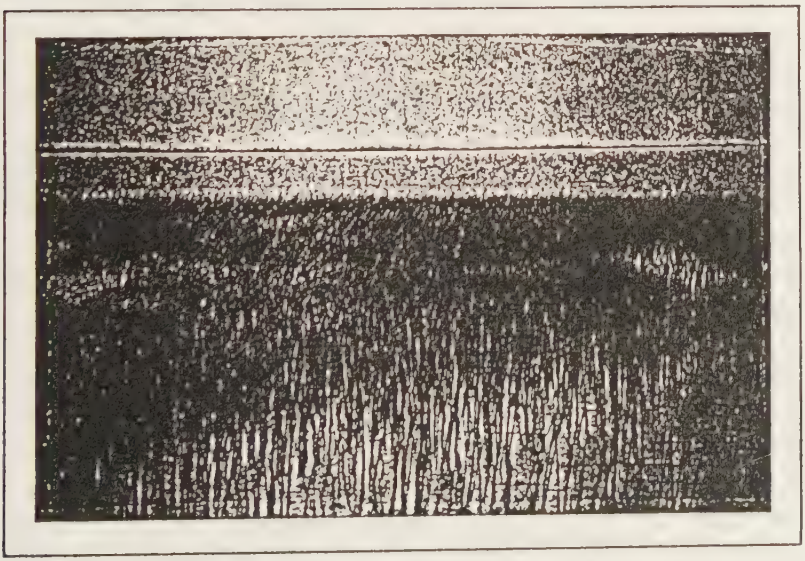


Photo 3: East margin (Fig. 4.B.5). View of *S.californicus* monospecific stands.

Field Procedure

Field investigations were carried out from August 1984 to March 1986 in nine selected lakes of the Restinga, and nine sites of Saco de Tapes (western margin of Patos Lagoon). Samples were taken during summer (from mid December to mid March), autumn (from mid March to mid June), winter (from mid June to mid September), and spring (from mid September to mid December).

Samples for water analysis were taken at 15 centimeters depth, with polyethylene bottles, from the middle of the littoral zone occupied by monospecific stands of *S.californicus*. After filtration *in situ*, and addition of sulfuric acid to pH less than 2, samples were preserved on ice and transported to the laboratory for analysis. Sediment samples were taken with a core and transported to the laboratory under deep freeze conditions. As underground parts of the emergent macrophyte (rhizomes and roots) were located in the upper 12 to 16 centimeters depth, only 20 centimeters sediments were analysed.

In the present work samples refer to the individual members, i.e., a square meter of each emergent macrophyte harvested at each site, and sample set refers to the entire data collection, i.e., the total area collected in the littoral zone, in each lake at a given time.

In order to compare the data and the results obtained, with other studies dealing with emergent macrophytes, the sampling method was standardized: all samples of a sample set were of the same size (one meter square harvested). The criteira commonly used to determine when a sample area becomes the recommended minimal area (GAUCH, 1985) was not applied since the area

was covered with a monospecific and homogeneous stand of *S.californicus*. As the study interest centered on variability within sites and seasons, and response of the monospecific stand to the environmental parameters, the samples of each sample set were 18 times replicated in a well-defined gradient, at fixed intervals, i.e., regular placement in a transect.

The species abundances were counts of individuals per square meter. Data from Saco de Tapes constitute part of other work (NHUCH VERLANGIERI, 1989) performed on the same area and at the same period. Biomass estimations followed WESTLAKE (1974), with some modifications.

Laboratory Analysis

Water analysis in the laboratory were performed according to STRICKLAND & PARSONS (1968), ZAHRADNIK (1981), AMERICAN PUBLIC HEALTH ASSOCIATION (1985) and FRESENIUS et al. (1988).

Total alkalinity was estimated by titration to pH 4.5 with standard acid. Chloride and sulphate concentrations were determined via the mercuric nitrate method and the turbidimetric method, respectively. Phosphate concentrations were determined via the ascorbic acid method after persulfate digestion. Nitrogen was determined by the Kjeldahl digestion method using a multiple digestion unit (FAITHFULL, 1969); ammonia via the indo-phenol-blue method; nitrate concentrations by the sodium-salicylate method. The phenantroline method was used to determine iron concentrations. Samples for total suspended solids determinations were Millipore filtered (0.45 µm) and total dissolved solids were determined by filtration and evaporation to dryness at 180°C. Organic matter was estimated by the chemical

oxygen demand via dichromate reflux method. Humic acids were estimated according to SANTOS & SANTOS (1970).

All material employed in collecting samples were pretreated according to the AMERICAN PUBLIC HEALTH ASSOCIATION (1985).

Sediment data were summarized by averaging triplicate samples at each 2 centimeters depth, for each parameter. Chemical parameters in sediments were analysed according to STRICKLAND & PARSONS (1968), ALLEN et al. (1974), ZAHRADNIK (1981), AMERICAN PUBLIC HEALTH ASSOCIATION (1985) and ALLEN et al. (1986).

Redox potential and pH were measured within 8 hours period after collection, by aqueous extracts with a pH meter and a potentiometer, respectively.

For analytical purposes sediments were dried at 60°C to a constant weight and grinding with a mill. Phosphorus was determined via the ascorbic acid method after persulfate digestion. Nitrogen was determined by the Kjeldahl digestion method using a multiple digestion unit (FAITHFULL, 1969, 1971). Estimates of available metals were obtained by extraction of the sediments for 2 hours with 0.5 M HCl (AGEMIAN & CHAU, 1976). A cold-extraction was preferred since the method do not attack the silicate fraction of the sediment and extracts the adsorbed, precipitated and complexed metals. Samples for calcium, potassium and sodium were analysed with an Eppendorf flame photometer. Magnesium concentrations and heavy metals were estimated with a Perkin-Elmer 5000 atomic absorption spectrophotometer.

Procedures for nutrient and metal analysis in plant material followed STRICKLAND & PARSONS (1968), ALLEN et al. (1974), ANDERSEN (1976), ZAHRADNIK (1981), AMERICAN PUBLIC HEALTH ASSOCIATION (1985) and ALLEN et al. (1986).

Total aboveground plant material was washed with distilled water, shared in inflorescences, leaves and stems, cut in small pieces with a stainless steel

scissors, weighed and oven dried to constant weight at 70°C. Dried material were weighed, randomly subsampled and analysed. Phosphorus was determined via the ascorbic acid method after persulfate digestion. Nitrogen was determined by the Kjeldahl digestion method using a multiple digestion unit (FAITHFULL, 1969, 1971).

Ignition in a furnace at 550°C for 1 hour was used for determination of calcium, magnesium, potassium and sodium in plant material. After treatment with hydrochloric acid for 6 hours, samples were filtered, diluted to a know volume and analysed with an Eppendorf flame photometer. Magnesium concentrations were estimated with a Perkin-Elmer 5000 atomic absorption spectrophotometer.

Extractions of zinc, copper, cadmium and lead followed a strong nitric acid digestion in a hot plate (170°C) for 5 hours. The extracts were diluted to a known volume and heavy metals were estimated with a Perkin-Elmer 5000 atomic absorption spectrophotometer.

During all analysis performed, the total quantity of acid used in each sample was included in the blank probe in order to substract the metal impurities resulting from the acid added. Two blanks were run in every eight samples. Blank readings were always very low and below the detection limits. In order to avoid systematic errors, a quantitatively known amount of pattern used to obtain the calibration curve was added to some selected samples as control.

Data Analysis

Sampling plant tissues is known to present some problems if the population is scarce and also because in some cases a representative part of plant is improbable to be satisfactory. In the present work, nevertheless, there is a sufficiently large and monospecific stand able to be statistically compared.

Each two sets of samples were compared by a t-test, using their means and standard errors with a confidence interval of 95%. The one-way analysis of variance (ANOVA) was performed to determine variations between and within sites and seasons. The relations between some parameters were investigated by the Pearson's product moment correlation coefficient (r).

The Factor Analysis, a statistical technique used to analyse the relationships among sets of many interrelated variables, was used to identify the relatively small number of factors that can be used to represent the littoral zone of the lake where macrophytes were collected. It derived from measurement of directly observable variables, in this case the nutrients as phosphate, nitrogen, calcium, magnesium, sodium, potassium, and the heavy metals as zinc, copper, cadmium and lead. The mathematical model for factor analysis appears similar to a multiple regression equation, differing by using labels for groups of variables or factors. To the analysis itselves were proceeded the correlation matrix for all the variables and the factor extraction. To compare water and sediments cores from the coastal lakes, a varimax rotation was used to minimize the variables with high loadings, and it was assumed that variables are uncorrelated with each other. The oblique rotation was used to represent each littoral zone separately, once this kind of rotation have often been found to yield substantively meaningful factors (SPSS,

1988). The estimates of the initial factors were obtained from Principal Components Analysis, which formed linear combinations of the observed variables. The first principal component was the combination that accounted for the largest amount of variance in the sample. The second and sucessives principal components explained the next largest and progressively smaller portions of the total sample variance, and all were uncorrelated with each other. The criterion to choose the number of factors to be used in the model was those that accounted for variances near or greater than 1.

The Bartlett's test of sphericity was used to test the hypothesis that the correlation matrix was an identity matrix. The measure of sampling adequacy was obtained through the Kaiser-Meyer-Olkin index where the magnitudes of the observed correlation coefficients were compared to the magnitudes of the partial correlation coefficients. The minimal value of the overall KMO statistic for this research was 0.70. In the same way, the measure of the sampling adequacy (MSA) for each individual variable was assumed to be higher than 0.70. The linear association among the variables computed through the squared multiple correlation coefficient between a variable and all other variables was assumed to be greater that 0.89.

Scirpus californicus (Mey.) Steud., 1841 (CYPERACEAE) was described taxonomically (BEETLE, 1941; BARROS, 1942; KOYAMA, 1963) but studies referring to the biology and ecology of this bulrush are lacking. HUTCHINSON (1975) followed the genus *Scirpus* dealing with species from the New World, and the genus *Schoenoplectus* referring to species from the Old World.

Regarding the literature, for a long time *S.californicus* was mistakenly referred as *S.riparius* and confused with *S.tatora* (BEETLE, 1941). Also in the past there was some confusion over the correct alignment of what were considered to be borderline species between the genus *Scirpus* and *Eleocharis*, the spike rush. The presence of involucrate bract and the comparatively well-developed mucronate blade and the absence of the reticulation of the style base in *Scirpus* differenciated the two genera (BEETLE, 1941).

S.californicus, a helophyte species, ranging from southern of North America to southern of South America, grows mainly in swampy areas and banks of lakes, rivers, and reservoirs. On a place where the species is established the sedimentation rate can increase and other species are able to occupy the new area. The aerial growth of the culms is assured by the reserves of the rhizome. The rhizome is the main site for the starch reserve. As soon as the culms show a photosynthetic capability, the leaves stop growing and are not persistent (TUR & ROSSI, 1976). The high seed production benefits the birds which use them as food. The transportation of seeds from aquatic plants in the alimentary tract of birds has been largely studied (HUTCHINSON, 1975). It is well known that by this manner and by seeds sticking to bird's feet in mud, the major

way of transportation may occur. Nevertheless, such mechanism of dispersal have not been observed in *S.californicus* up to the present. Aerial dispersal of seeds by wind and transportation by water movements certainly are important ways of dispersal in such littoral zones. In this case new colonies of *S.californicus* are able to be formed in other places.

This bulrush commonly found in lakes of the Coastal Plain of Rio Grande do Sul shows a fairly constant growth throughout the year, although reduced during winter. During summer the bulrushes show an increase in density and during autumn a dry state is observed in the culms.

TUR & ROSSI (1976) have observed a differential growth of the rhizome between summer and winter. In the latter, the growth is very low and the formation of up to 4 culms interrupts the growth of the first one. The process of senescence of the oldest culms occurs during the entire growth period, but is notorious in winter. This is due to the development of lateral buds which follow the senescence state of the floriferous culms formed during winter (TUR & ROSSI, 1976). These authors also have observed that the development of inflorescences formed during this period occurs until the beginning of the spring, and culms formed after spring are vegetative, but reduced or sterile inflorescences may appear.

ROSSI & TUR (1976), studying the rhizome of *S. californicus* in lakes of third-rate and rivers of Buenos Aires province, have found that the colonization occurs very quickly and the species tends to overtake entirely the area. Rhizome begins to grow during winter and the development is completed in the beginning of the spring (ROSSI & TUR, 1976). After that, an accelerated development occurs until the end of the summer. Annually a main rhizome is able to grow up to 2 meters, showing many lateral branches which can reach aproximately 1 meter length. The rhizome shows a negative phototropism

and a diageotropism. Nevertheless, if the sediment is very hard due to calcareous precipitation, and if it shows a slime surface, the rhizome develops haptotropism.

An esclerosis process and an increase in size is acentuated in rhizomes located at places where the water level fluctuates periodically. Nevertheless, after a dry period the rhizome shows a notable regeneration when hydrated (ROSSI & TUR, 1976). These authors also mentioned that rhizomes grow efficiently in every type of soil, but their size depends on the soil aeration. Climatic changes such as temperature also play an important role in the rhizome structure. Although the water level limits the growth of the vegetation to the shallow zones of the lakes, this bulrush is able to grow in zones where the water level reaches only a few centimeters and is not permanent.

Although TUR & ROSSI (1976) have not observed any important morphological differences between stands of *S.californicus* in lakes and marsh areas, I have always found some structural differences between stands located in Saco de Tapes. The height and density of the bulrushes varied from bank to bank, according to anthropogenic influences and location and exposition of the littoral zone to abiotic factors such as wind and wave action. TUR & ROSSI (1976) have also mentioned that culms which are constantly submersed show an increase in height and density.

A peculiar feature of the bulrush is its capacity to bend with the wind. This is partially due to a suitable anatomy in conjunction to very alongate or very narrow stems presented by plants in disturbed habitats (HUTCHINSON, 1975). Also rhizome hardness is important since this property enable plants to grow on gravelly bottom (HUTCHINSON, 1975), and such differentiation is a valuable factor regarding macrophyte distribution.

SOURCES AND CHARACTERISTICS OF THE ELEMENTS

Heavy Metals

The natural concentration of trace metals in soils is wide, and the main sources are natural geological materials. Release of metals through weathering processes and transport to aquatic systems depend significantly on their occurence in igneous, metamorphic and sedimentary rocks (SALOMONS & FÖRSTNER, 1984) and on the intensity of the processes. The normal abundance of an element is commonly referred in earth material as "background" and the value is a result of the nature of the material (Table 2) (THORNTON, 1981).

Table 2: Mean concentrations of selected metals (ppm) in igneous and sedimentary rocks (after THORNTON, 1981).

element	Basaltic igneous	Granitic igneous	Shales & Clays	Black shales	Lime-stones	Sand-stones
zinc	100	40	90	100	20	16
copper	90	15	50	70	4	2
cadmium	0.20	0.15	1.40	1.00	0.05	0.05
lead	6	18	20	30	9	12

The "background" concentrations for heavy metals in sediments, based on the average shale composition assumed as a global standard value, the fossil sediments from defined aquatic environments as a standard, and recent deposits in relatively unpolluted areas (SALOMONS &

FÖRSTNER, 1984) are showed in Table 3. Nevertheless, freshwater sediments are likely to show many discrepancies regarding heavy metal contents if compared to sediments along the Brazilian coast (Table 4).

Table 3: Background concentrations of some heavy metals (ppm) in sediments (after SALOMONS & FÖRSTNER, 1984).

element	sub-recent Rhine sediments	lacustrine sediments
zinc	115	118
copper	51	45
cadmium	0.30	0.40
lead	30	34

In lakes heavy metals are introduced by atmosphere and riverine inputs and many kinds of waste discharges (SALOMONS & FÖRSTNER, 1984). Once metals enter an aquatic system they are quickly incorporated into suspended and bottom sediments (CLINE & CHAMBERS, 1977). Allochtonous particles will partially settle to the bottom and dissolved heavy metals can be removed by adsorption, uptake by biota and incorporation on authigenous phases, whereas a strong interaction occurs in the epilimnion with the carbon cycle and in the anoxic hypolimnion with the redox cycle (SALOMONS & FÖRSTNER, 1984).

The increasing industrialization and population density, can be detected through the sediments of freshwater lakes that provide the means for assessing the metal contamination in aquatic systems (FÖRSTNER, 1976,

1977), as well as for tracing both regional distribution patterns and chronological variations of metals due to anthropogenic influences (FÖRSTNER, 1977; FÖRSTNER & WITTMANN, 1981; SALOMONS & FÖRSTNER, 1984).

Table 4: Mean metal concentrations (ppm) of freshwater sediments and sediments of some sites along the Brazilian coast.

	Zn	Cu	Cd	Pb
Lakes in:[1]				
Amazone	156	58	0.34	33
East-African Rift	159	39	0.64	13
Australia	93	46	0.33	37
Eurasia	122	47	0.53	33
Brazilian coast:[2]				
Todos os Santos Bay	5-2400	5-55	1-120	10-960
Sepetiba Bay	24-121	2-166	0.5-8.7	6.5-8.7
Guanabara Bay	78-124	91-731	2.5-3.1	22-43
Santos Bay	20-81	0.4-19	0.25	3-47
Patos Lagoon[3]	20-214	0.8-20	0.1-20	8-267

[1] after FÖRSTNER, 1977
[2] after PFEIFFER et al., 1988
[3] after BAISCH et al., 1988

OLIVER (1973) reported the increase of heavy metal concentrations in river sediments and identified sources of discharge into them. He stated that finer sediment samples generally contained more heavy metal concentrations than coarser samples. Although chemical and physical variables contribute to some heavy metal redistribution, the relation between grain size and concentrations of heavy metals with depth was also observed by CLINE & CHAMBERS (1977). Sediments showing an upward concentration gradient of heavy metals may indicate that biochemical factors and biological activity in the upper strata are effective in causing the gradients, but the concentration gradients are not entirely grain size dependent. The metal concentrations in an area relatively free from direct cultural inputs are redistributed as a result of geochemical and/or physical factors (CLINE & CHAMBERS, 1977).

Industrial emissions can increase the cadmium level within the upper layers of the sediments. The enrichment of metals as cadmium, lead and zinc studied through sediment cores can reflect the "civilizational influences" also during the past (FÖRSTNER, 1977, 1982; EVANS & DILLON, 1982). MATHIS & KEVERN (1975) have mentioned that migratory geese and waterfowl utilizing a relatively small lake, in southwest Michigan, for resting and feeding, leave substantial quantities of cadmium and lead in the lake. Cadmium can accumulate differently in the many components of an aquatic system. ENK & MATHIS (1977) have reported that cadmium concentrates in both fishes and sediments in similar levels, but much less than the mean concentration in aquatic insects. In terrestrial systems cadmium is taken up by plants more easily than most of other heavy metals (SALOMONS & FÖRSTNER, 1984), and can reach levels that are toxic to animals before the vegetation is damaged. Moreover, high

sedimentation rates related to river overflow seem to increase heavy metal concentrations in the soils (SIEBER, 1987). With respect to sediment transport, lakes are nearly closed systems and sediment loadings and sedimentation rates are high even when accumulation is restricted almost to fine sediments. Nevertheless, the sediments can be redistributed by physical processes, in shallow lakes, mainly due to the energy of the wind.

Increasing concentrations of zinc and lead, as well as nitrogen and phosphorus can be a result of a public sewage system. Mine and industrial waste disposal are also sources of lead in surface waters (ENK & MATHIS, 1977).

It is well known that lead is widely scattered throughout the environment by the combustion of gasoline and other fossil fuels (ENK & MATHIS, 1977) and increasing lead concentrations in sediments of natural waters could be explained by proximities to heavy traffic roadways. Defined gradients of lead contamination besides roadways (O'NEILL et al., 1983), and less-defined gradients of cadmium, copper and zinc, among others, have been documented in soils, plants and atmosphere (FREEDMAN & HUTCHINSON, 1981). Also high concentration of lead in a river near the city of Ottawa was a direct result of dumping snow containing lead from automobile exhausts (OLIVER, 1968).

Limnic organisms are good indicators of pollutants in their corresponding habitat (MÜLLER, 1986). Furthermore, after heavy metals enter an aquatic system, organisms living in contact with sediments tend to accumulate them more than those not in contact with sediments (FÖRSTNER & WITTMANN, 1981). In fact, aquatic snails are known to show the higher concentrations of lead than those values found in sediments (ENK & MATHIS, 1977).

Metal compounds can be released from sediments through natural or synthetic chelating substances present in the water. By this means cadmium and copper are highly stable in natural waters. Nevertheless, the metals differ in their ability to chelate (SALOMONS & FÖRSTNER, 1984) and the uppermost layer of sediments are enriched by the more easily chelated metals. Under anoxic conditions copper may escape the sediments to the surface waters, and copper/zinc will contrast according to the oxidizing and anoxic conditions of deposited sediments (SALOMONS & FÖRSTNER, 1984; FREVERT & SOLLMANN, 1987).

Heavy metal contaminations in highly polluted areas coincide with organic substances both originating from industrial, rural or public sludge (FÖRSTNER, 1977, FÖRSTNER & WITTMANN, 1981). Co-precipitation and sorption of metals on hydrous oxides are the principal mechanisms controlling the heavy metal distribution in aerated water systems and the uptake or release of these metals depends on the pH, the metal ion concentration, the concentrations of other heavy metals being present in solution, and the amount and type of organic and inorganic complexes (JENNE, 1968; FÖRSTNER, 1977, 1982; FÖRSTNER & WITTMANN, 1981; SALOMONS & FÖRSTNER, 1984; ALLARD et al., 1987). By this way, a depletion of oxygen causes a release of toxic metals into the water. The rates of solubility of heavy metal compounds increase at low pH values and thus the sorption on clay minerals, humic substances, and hydrous oxides decrease (LOCKWOOD & CHEN, 1973). This means that increasing pH represents an increase on metal adsorptions. Sorption of heavy metals on organic substances and complexes, and metal oxides were already largely discussed (SINGER, 1977; SALOMONS & FÖRSTNER, 1984; SAGER, 1988). For heavy metal contaminants such as copper, cadmium, lead and zinc, among others, the hydrous oxides of aluminium, iron, and

manganese may play important roles (LEE, 1975; SALOMONS & FÖRSTNER, 1984), but the age of the hydrous metal oxides can alter the interaction with heavy metals and other chemical contaminants (LEE, 1975). Manganese and iron originated from groundwater system and present in reduced oxidation states can enter aquatic systems where they are oxidize to the hydrous metal oxide (LEE, 1975). Furthermore, metals co-precipitated as hydroxides are less available to biota than metals adsorbed on particles (GRAHN & HÅKANSON, 1987). FREVERT & SOLLMANN (1987) have mentioned that copper, zinc, cadmium and lead would rapidly be precipitated when sulfide-sulfur concentrations are regulated in sediment-water systems, and the release rates of zinc exceed the ones of copper when the overlying water is changed to well oxygenated conditions. HOLMES et al. (1974) also mentioned such precipitation of cadmium with sulfide ions. However, a desorption due to increasing oxygenation was detected. In a dynamic system, however, the metals are chelated before they reach the sulfide layer (SALOMONS & FÖRSTNER, 1984).

Metal pollution in natural water systems is a function of complex interactions between water and particulate matter. The transport of heavy metals is largely influenced by the organic matter which bind them and by suspended particles that are covered with organic films (SALOMONS & FÖRSTNER, 1984). Remobilization of heavy metals from suspended material and sediments is mainly caused by chemical changes in waters (FÖRSTNER & WITTMANN, 1981) as elevated salt concentrations, changes in the redox conditions, lowering of pH and increased use of natural and synthetic complexing agents. Also biochemical transformation processes play an important role in the metal remobilization from sediment to animal or plant.

In terrestrial systems, plants have been used as indicators of heavy metal levels since in an area or geographic region their association with a particular metal is recognized. Nevertheless, different species growing on the same area can show different concentrations of the same heavy metal (ANTONOVICS et al., 1971; SIEBER, 1987). A list of indicators and heavy metal tolerants plants is given by ANTONOVICS et al. (1971).

Lead content of plants normally reflects the extent of the biologically available form, since in terrestrial systems organic or colloidal materials are known to reduce the uptake by plants (KOEPPE, 1981). Aquatic macrophytes show no marked tendency for accumulating lead in different parts of the plant (HUTCHINSON, 1975). In some submerged macrophytes lead and cadmium uptake is made through both water and sediment (MAYES & McINTOSH, 1977).

Cadmium concentrations vary among species and different parts of the plants mainly influenced by its "physiological state of development" (PAGE et al., 1981), and visual damage is not often observed (MacLEAN, 1979). Cadmium occurs naturally in the environment and uncontaminated areas are representative of natural backgrounds. PAGE et al. (1981) present a list of background levels of cadmium for crops. In aquatic macrophytes cadmium appears to be related to zinc contents (HUTCHINSON, 1975).

In terrestrial systems, zinc and copper are elements that produce problems if occurring both in deficiency or excess. Copper deficiency induces morphological changes mainly related to lignification, whereas copper excess is related to the root system growth (LEPP, 1981). However, in many cases, the binding of copper with soil organic matter content promotes an immobilization of the metal.

Furthermore, copper uptake by plants is regulated by nitrogen in the soil (LEPP, 1981). Zinc availability to plants, on the other side, is highly dependent on chelation processes in soils, as well as on temperature and oxygen (COLLINS, 1981). In aquatic systems, different species of macrophytes growing in the same locality can show different concentrations of both copper and zinc (compare HUTCHINSON, 1975). Moreover, zinc and copper contents in some submerged macrophytes seem to be more related to the sediment in which the plant is rooted than to water concentrations. Once sediments accumulate zinc and copper, a rapid uptake of these metals by submerged macrophytes seems to occur (CUSHING, Jr. & THOMAS, 1980). *P.australis* growing in polluted lakes appears to show some resistance to copper enhancement (HUTCHINSON, 1975) whose excess is mainly restricted to the immersed parts. In unpolluted lakes copper in rhizome is likely to be related to copper contents in sediments. On the other hand, in most of the aquatic macrophytes, tissue zinc seems to be more abundant than copper. Low zinc contents are found normally in emergent macrophytes of the genus *Typha* (HUTCHINSON, 1975).

Nutrients

Various species of aquatic macrophytes are regulated in lakes by chemical factors. Depending on the plant species, nutrient supplies are made through both sediment and water, and the uptake depends on the relationship between structure and function (HUTCHINSON, 1975).

Rainfall, agricultural processes near the aquatic system and sewage effluents are some of the nitrogen sources in lakes. Generally, in aquatic systems plants use ammonia or nitrate-nitrogen as source for synthesis

of proteins, pyrimidines, and purines, and other forms of organic nitrogen (McCARTY, 1969; BREZONIK, 1972). Some of organic nitrogen derived from the decomposition of both plants and animals is transformed into ammonia-nitrogen by biological processes. On the other hand, in aerobic conditions ammonia is oxidized to nitrite and nitrate. In the epilimnion of lakes nitrate is lowered by high phytoplankton densities (RYBAK, 1972; SCHELSKE & STOERMER, 1972; MARSHALL & FALCONER, 1973; STEWART & MARKELLO, 1974; STONEBURNER & SMOCK, 1979) and by macrophytes (KLEEREKOPER, 1940; GOULDER & BOATMAN, 1971; BREZONIK, 1972). Use of ammonia by submerged macrophytes had already been reported (TOETZ, 1973, 1974; MULLIGAN et al., 1976). More recently, MIYAZAKI & ICHIMURA (1986) and MIYAZAKI et al. (1987) have demonstrated that nitrate and ammonia uptake by phytoplankton depends on depth and light conditions.

Nitrogen and phosphorus are the two nutrients more likely to be limited in aquatic systems, and often related to enhancement of lake eutrophication. Nitrogen becomes limiting nutrient mainly due to the slow rate of atmospheric fixation and slow degradation rate of the organic form (McCARTY, 1969). Moreover, effluents from waste treatment plants introduce soluble nitrogen and phosphorus in the aquatic system, which are readily available to biota. Problems induced by detergent phosphates are not new in aquatic systems. Furthermore, the replacement of phosphates by sodium salt of nitrilotriacetic acid (NTA) seems to be a more dangerous solution since this substance shows some ability to complexe with heavy metals (DUTHIE, 1972; GILBERT & DE JONG, 1978). Furthermore, this substance can accelerate eutrophication processes since intermediate products during its decomposition can be used as nitrogen source by some species of algae or may be "deaminated" to

ammonia and consequently available to phytoplankton (RYTHER & DUNSTAN, 1971). Condensed phosphates, largely used in detergents and in water treatment, are also generated by organisms (McCARTY, 1969) and hydrolized to the orthophosphate form (CLESCERI & LEE, 1965). In this form, assimilation by aquatic plants occurs, and particulate organic phosphorus is formed. The unavailable form may settle on bottom sediments in lakes. REID (1961) listed some factors that determine the concentration of total exchangeable phosphorus in natural aquatic systems as follows: basin morphometry, chemical composition of the geological formation of the area, drainage area characteristics, and organic metabolism and rate of loosing phosphorus to sediments. Phosphorus in sediments is bound as ions on clay mineral, organic matter and hydroxy gels, and present as insoluble salts (KRAMER, 1972; RIEMER, 1984). Furthermore, its release is highly dependent on pH and oxygen concentrations in water. Nitrogen is more soluble and an equilibrium system between sediment and water does not occur as it does for phosphorus.

In tropical regions nitrogen and phosphorus contents in aquatic macrophytes are normally higher than those levels of nutrients in the water of the littoral zone or in the lake (HOWARD-WILLIAMS & JUNK, 1977; BARBIERI et al., 1984). In some aquatic macrophytes, phosphorus level is rather regulated by genetic differences between species than by the quantity available in the system (HUTCHINSON, 1975). BOYD & HESS (1970) have reported some variations in nutrient concentrations in *Typha* as resulting from genetic differences due to hybridization. Nevertheless, concentrations of nitrogen and phosphorus in tissues of some marsh plants seem to be affected by their availability. From experimental tests, SHAVER & MELILLO (1984) have pointed out that phosphorus and

nitrogen uptake efficiency by marsh plants decreases with increasing nutrient availability, probably due to "saturation of the plants' uptake capacity". On the other hand, phosphate absorption by marsh plants seems to be temperature dependent (CHAPIN, 1974).

In tropical waters, nevertheless, nitrogen is commonly a limiting factor and phosphorus plays a second role in the system, contrary to what occurs in temperate lakes (PAYNE, 1986).

Potassium is one of the most abundant elements present in plant tissues (HUTCHINSON, 1975). Its concentration, however, varies among different aquatic plants. The lowest mean concentration was found in *T.latifolia* in Polish lakes (BERNATOWICZ, 1969), but it seems likely that estimated mean for terrestrial plants is lower (HUTCHINSON, 1975).

Sodium appears to be more variable in plant tissues than potassium, but varies among plant species and according to the plant age (HUTCHINSON, 1975). HUTCHINSON (1975) had mentioned that if sodium content in terrestrial plants is very low, terrestrial herbivorous can find "accessible source of sodium" in the aquatic macrophytes.

Calcium and magnesium are the most abundant ions in freshwaters. Both elements show similar chemical activity and may limit biological processes (REID, 1961). Magnesium levels in aquatic plants occur within the ranges observed for terrestrial vegetation (HUTCHINSON, 1975). Generally, in many aquatic macrophytes, no differences in calcium contents are observed between parts of the plant. Increasing calcium contents, nevertheless, is sometimes related to precipitation process in obtaining carbon dioxide for photosynthesis (REID, 1961; HUTCHINSON, 1975).

RESULTS AND DISCUSSION

WATER CHEMISTRY

Variations in concentrations of some water parameters measured in the littoral zone of coastal lakes as well as in the Saco de Tapes (Table 5) reflect the geochemistry of the area, local differences and mixing features.

Table 5: Chemical composition of water in the littoral zone of Saco de Tapes and coastal lakes during summer. Means and standard deviations are based on triplicate determinations.

	Saco de Tapes (n=9)			coastal lakes (n=9)		
	mean	s	CV(%)	mean	s	CV(%)
alkalinity (me/l)	0.41	0.16	39.88	0.34	0.10	30.24
chloride (mg/l)	59.94	68.92	114.98	41.44	26.82	64.72
sulphate (mg/l)	9.66	1.72	17.77	7.33	3.58	48.83
organic matter (mgO_2/l)	17.87	3.02	16.90	24.87	15.04	60.49
iron (mg/l)	1.76	0.90	50.97	0.58	0.85	146.56
phosphorus (mg/l)	0.19	0.10	55.20	1.92	1.28	66.88
nitrogen (mg/l)	0.26	0.13	49.72	1.22	0.61	50.09
N-ammonia (mg/l)	0.01	0.01	109.87	0.50	0.56	113.25
N-nitrate (mg/l)	0.05	0.01	24.10	2.23	0.41	18.50
humic acids (mg/l)	20.03	7.20	35.94	17.19	9.54	55.50
dissolved solids (mg/l)	0.23	0.12	52.56	-	-	-
suspended matter (mg/l)	0.03	0.01	40.82	-	-	-

It is largely known that chemical composition of water in littoral zones differs from water characteristics in the central part of the lake (BJÖRK, 1967; PIECZYNSKA, 1972; PRIBIL & DVORAK, 1973). Hydrodynamic and climatic factors, associated with the occurrence or absence of macrophyte stands, influence greatly the chemical properties of water in the littoral.

The data presented in Fig. 5 emphasize the contrast in margins of Saco de Tapes during summer. A small reversed chloride gradient can be seen in the southmost margins, compared to the north portion of the system. An inverse trend is observed to suspended matter, humic acids and total iron concentrations.

A negative correlation between suspended matter and chloride concentrations (Fig. 6) (Table 6) demonstrates that precipitation may occur mainly in the southmost margins of the Saco de Tapes system. The equation describing the relationship between chloride and suspended matter for the littoral zone of Saco de Tapes shows that

$$\text{SUSPENDED MATTER} = 0.038 - \text{CHLORIDE}$$

with $r=-0.881$ and $P<0.001$.

Figure 5: Percent deviation of the mean chemical concentrations of water in the littoral zone of Saco de Tapes. Numbers below correspond to those margins referred in Fig. 4.B.

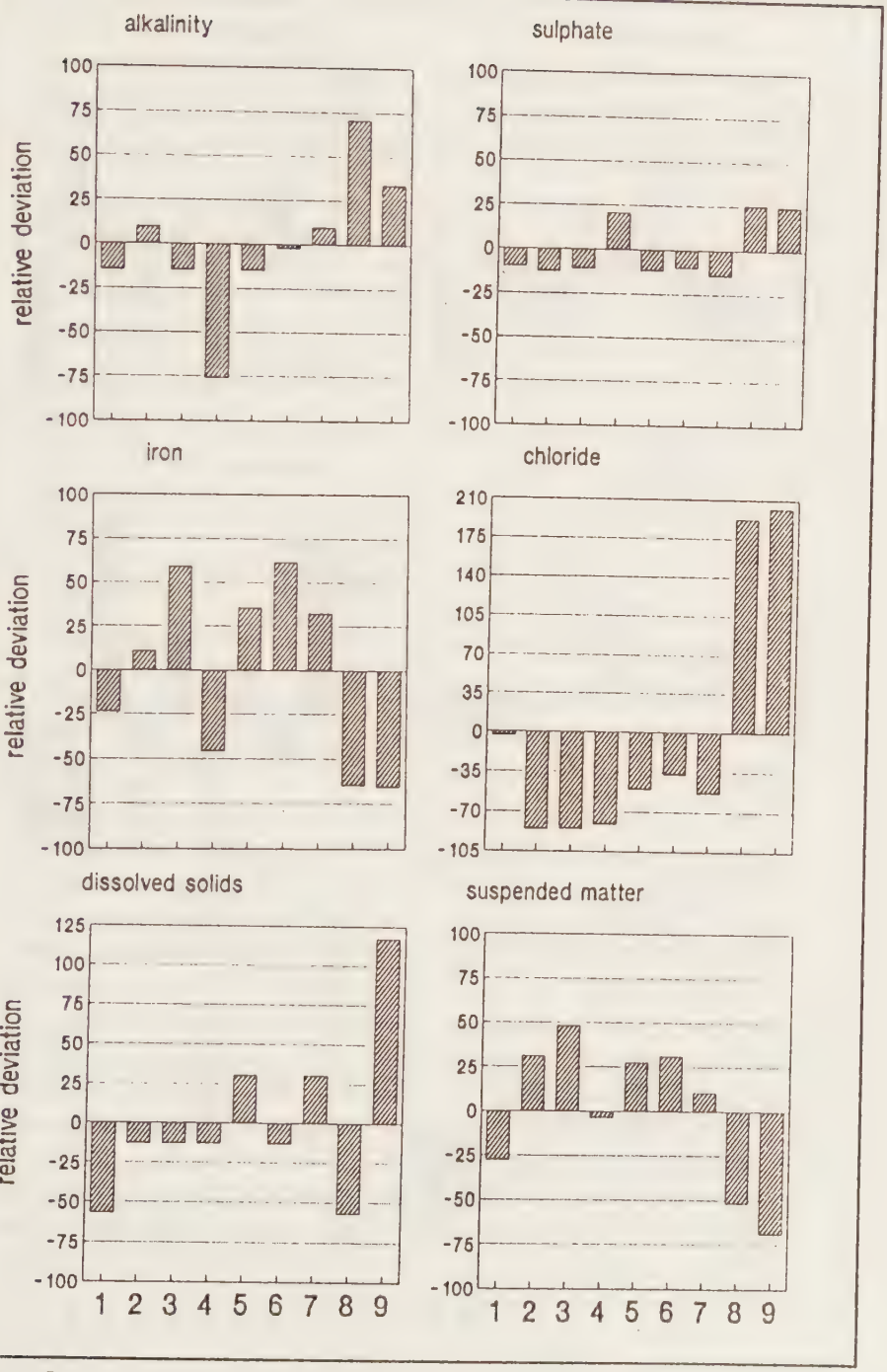
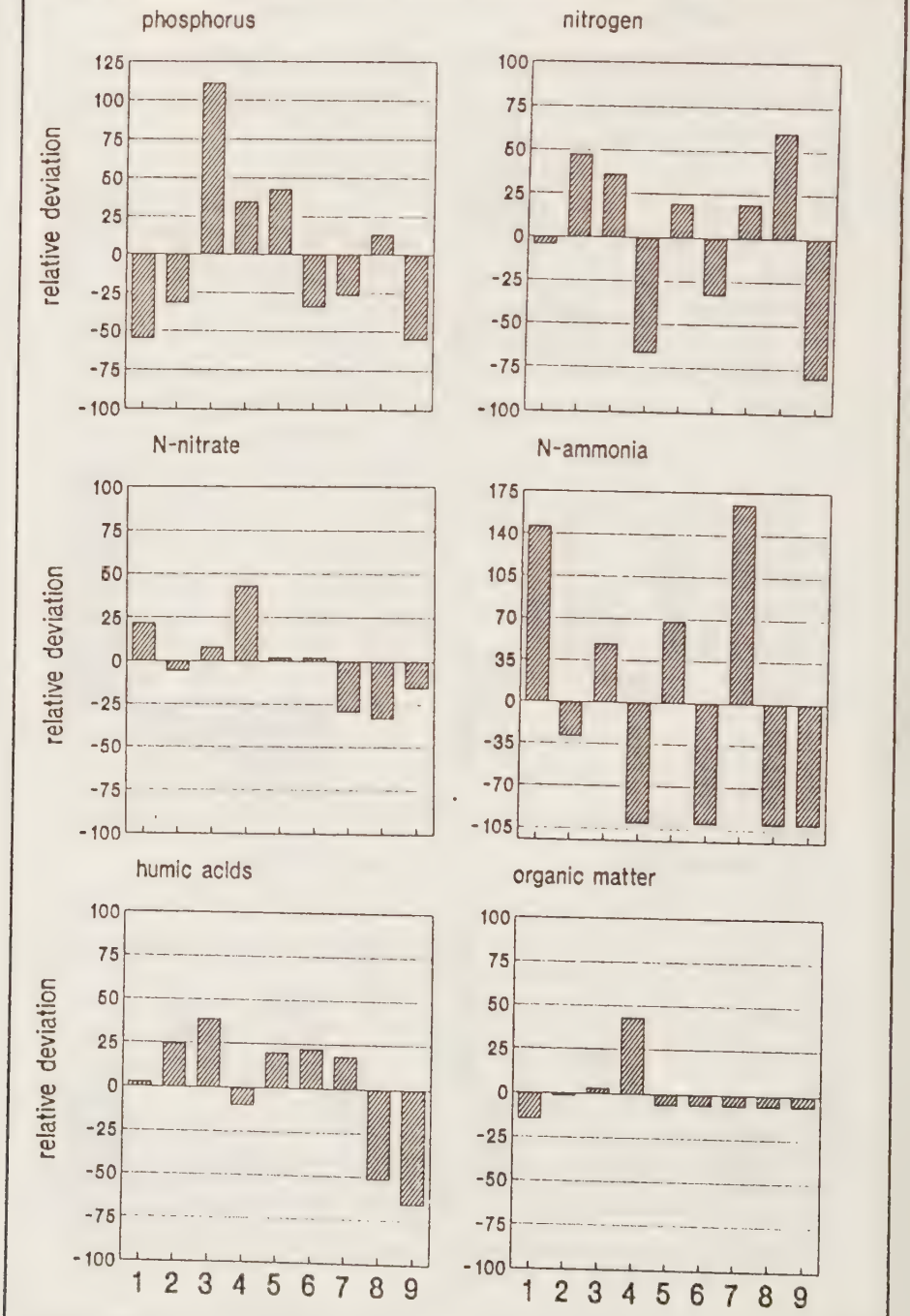

alkalinity
sulphate
iron
chloride
dissolved solids
suspended matter
relative deviation
relative deviation
relative deviation
100
75
50
25
0
-25
-50
-75
-100
210
175
140
105
70
35
0
-35
-70
-105
125
1 2 3 4 5 6 7 8 9

Fig. 5


phosphorus
nitrogen
N-nitrate
N-ammonia
humic acids
organic matter
relative deviation
relative deviation
relative deviation
125
100
75
50
25
0
-25
-50
-75
-100
100
75
50
25
0
-25
-50
-75
-100
100
75
50
25
0
-25
-50
-75
-100
175
140
105
70
35
0
-35
-70
-105
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-25
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-75
-100
1 2 3 4 5 6 7 8 9
1 2 3 4 5 6 7 8 9

Fig. 5

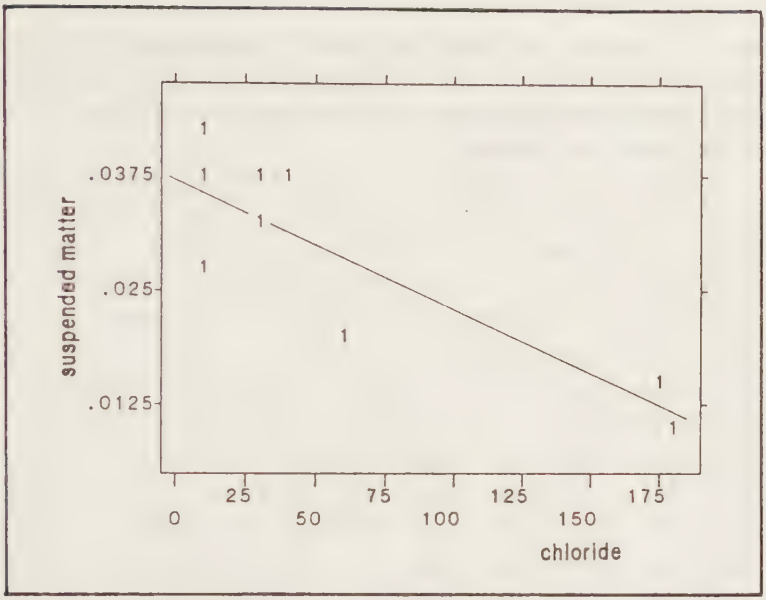


Figure 6: Relationship between suspended matter and chloride.

Readings of alkalinity ranged from 0.10 me/l in the northeastern edge to 0.70 me/l in the south portion. Acid conditions were recorded only in the northeast margin where a canal drains water from a swamp area into the system.

Nitrate-nitrogen and ammonia are the most important forms of nitrogen in freshwaters. Nitrate in the epilimnion of lakes is known to be lowered by high phytoplankton densities (RYBAK, 1972; SCHELSKE & STOERMER, 1972; MARSHALL & FALCONER, 1973; STEWART & MARKELLO, 1974; STONEBURNER & SMOCK, 1979) and by submerged macrophytes in running waters (KLEEREKOPER, 1940).

Table 6: Simple correlation coefficients based on water analysis variation in the littoral zone of Saco de Tapes. Levels of significance for P<0.05(*), P<0.01(**) and P<0.001(***) are given.

	alka	Cl	SO_4	o.m.	Fe	PO_4	N	NH_4	NO_3	h.ac.	dis.	susp
alka	1.0											
Cl	.75*	1.0										
SO_4	.23	.74*	1.0									
o.m.	-.68*	-.33	.40	1.0								
Fe	-.25	-.72*	-.86**	-.21	1.0							
PO_4	-.31	-.34	-.04	.40	.32	1.0						
N	.41	-.16	-.42	-.40	.32	.32	1.0					
NH_4	-.15	-.42	-.70*	-.40	.41	.19	.37	1.0				
NO_3	-.88***	-.46	-.01	.58	.01	.22	-.50	-.05	1.0			
h.ac.	-.49	-.92***	-.90***	-.01	.90***	.35	.38	.51	.23	1.0		
dis.	.10	.28	.19	-.05	..08	-.20	-.53	-.10	-.23	-.31	1.0	
susp	-.43	-.88***	-.84**	.03	.91***	.50	.46	.47	.15	.98***	-.33	1.0

In the littoral zone of Saco de Tapes nitrate-nitrogen showed a slight enhancement in those margins where incoming water from swampy areas reaches the system (northeast, 0.073 mg/l) or where canals for agricultural purposes were constructed (southwest, 0.062 mg/l). Ammonia was high not only in the southwestern edge (29.23 µg/l), but also in the "esporão" (31.53 µg/l). Both margins constitute the southmost limits of the Saco de Tapes system, and separate this system from the Patos Lagoon itself. Nevertheless, compared to values found by ESTEVES et al. (1984) in Rio de Janeiro's coastal lakes, nitrate concentrations in the littoral zone of Saco de

Tapes were slightly higher, but in the range of values mentioned by PIECZYNSKA (1972).

Iron was relatively high in the littoral water (mean of 1765.19 µg/l), but a slight decrease was observed in the southern margins (610.16 and 625.16 µg/l, in the south and in the southbay, respectively) and in the northeast (960.33 µg/l). Almost the same trend obtained for iron concentrations, was observed on humic acids. The lowest values were noted in the southmost margins (6.96 mg/l in the south, and 9.78 mg/l in the southbay), and a slight decrease in the northeast (18.05 mg/l). All other values were above 20.49 mg/l. As humic acids show some ability to form complexes with colloidal iron, the partitioning of phosphorus can be affected. In aerobic medium of alkaline pH, humic acid alters the phosphorus adsorption properties of iron hydroxide, and the alteration is highly dependent on the degree of complexation of the iron by humic acids (YOUNG & COMSTOCK, 1986).

Phosphorus-phosphate concentrations were by far higher in Saco de Tapes than values mentioned by ESTEVES et al. (1984) for the coastal lakes in Rio de Janeiro, and by BRINKMANN (1986) for clearwater streams in the Amazonian region. Values obtained in the littoral zones occupied by *Phragmites* stands (PRIBIL & DVORAK, 1973) were relatively low compared to those found in the littoral zone dominated by *S.californicus*. Nevertheless, the results obtained in Saco de Tapes are in the range of values mentioned by PIECZYNSKA (1972) for some eulittoral zone in Polish lakes.

Sulphate concentrations were always within the 25% limits of the mean. Organic matter was slightly higher in the northeastern edge, certainly due to the presence of the canal which drains water from the swampy area.

Many factors could be responsible for the great variations observed in some chemical parameters evaluated

in the littoral zone of the lakes (Table 5). Many differences among them may be related to shoreline configuration, erosion and accumulation processes, and changes in water level. Chemical characteristics showed by Barros Lake (ARAUJO DE OLIVEIRA, 1990a) are nearly found in the littoral zone dominated by *S.californicus* in the same lake. Due to the location of such area in an open shore, on the western margin, wind-induced waves promote a constant mixing also in the littoral zone. By this way, since the sediments are constantly resuspended in the entire water mass, chemical conditions of water in the littoral zone present almost the same features as in the whole lake.

Chemical characteristics of water in the littoral zones of the coastal lakes (Fig. 7) distinguish Caieira and Barros lakes with great amounts of nitrogen and organic matter. The selected lakes located at the southmost portion of the Coastal Plain seemed to show the lowest organic matter contents. Humic acids and N-amonia were relatively high in Barros Lake, when compared to other lakes. Furthermore, in the southmost lakes (Barros-Solidão and Tarumã), and in Caieira Lake, humic acids were low. N-nitrate, on the other hand, showed no tendency among all of them. All nitrogen forms were higher in the coastal lakes, compared to water analysed in the *S.californicus* stands of Saco de Tapes.

Palmital Lake was the only one that presented a great amount of total iron, followed by Barros Lake. Values of total iron in water of Saco de Tapes, nevertheless, were slightly higher than those found for the coastal lakes. Probably the nature of the basement of Saco de Tapes, as well as of Barros and Palmital lakes plays an important role in the iron levels. Furthermore, as Saco de Tapes constitutes a part of the Patos Lagoon, several mineral elements carried with the flowing water from the

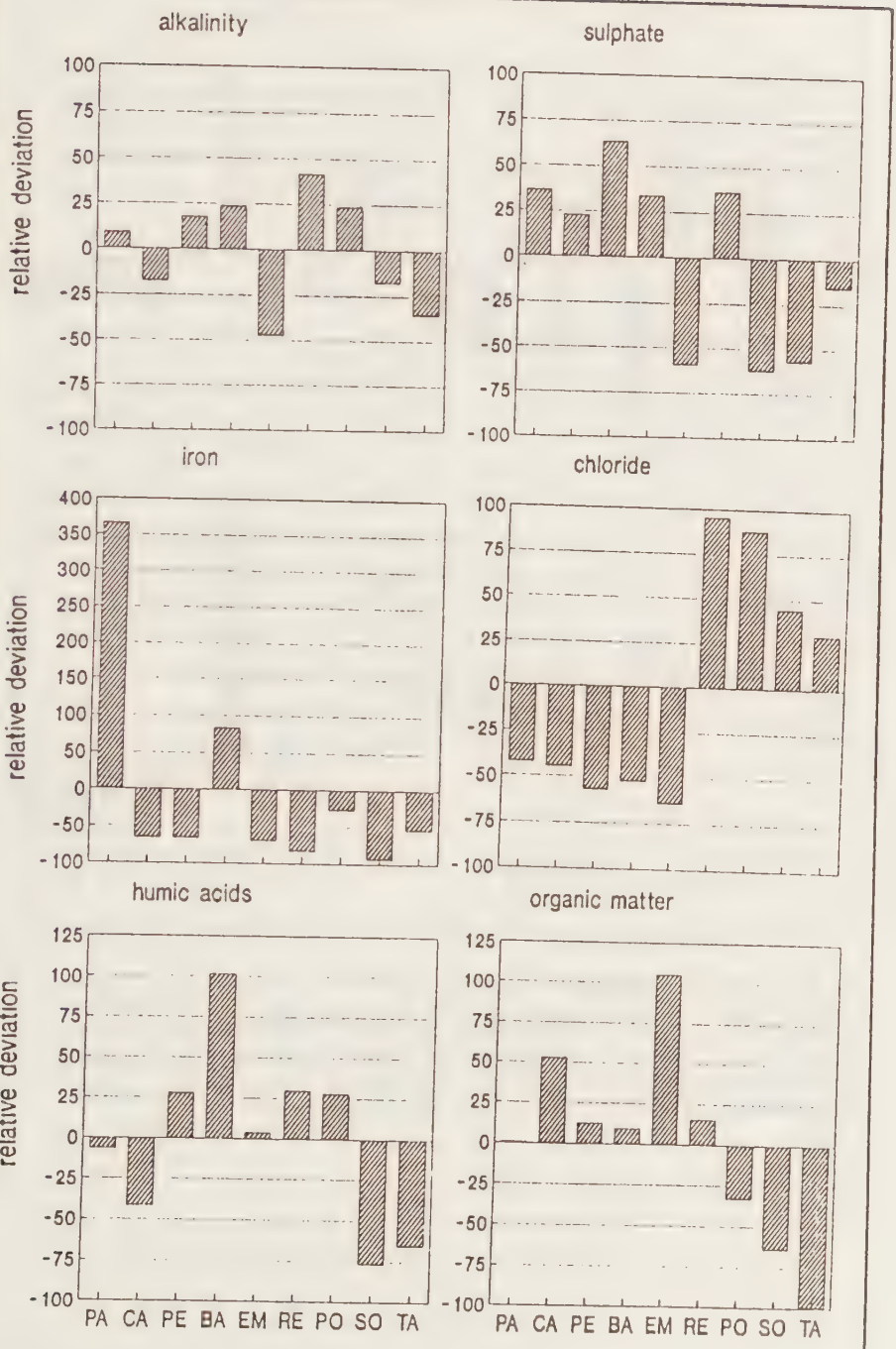

alkalinity
sulphate
iron
chloride
humic acids
organic matter
relative deviation
100
75
50
25
0
-25
-50
-75
-100
400
350
300
250
200
150
125
PA CA PE BA EM RE PO SO TA

Fig. 7

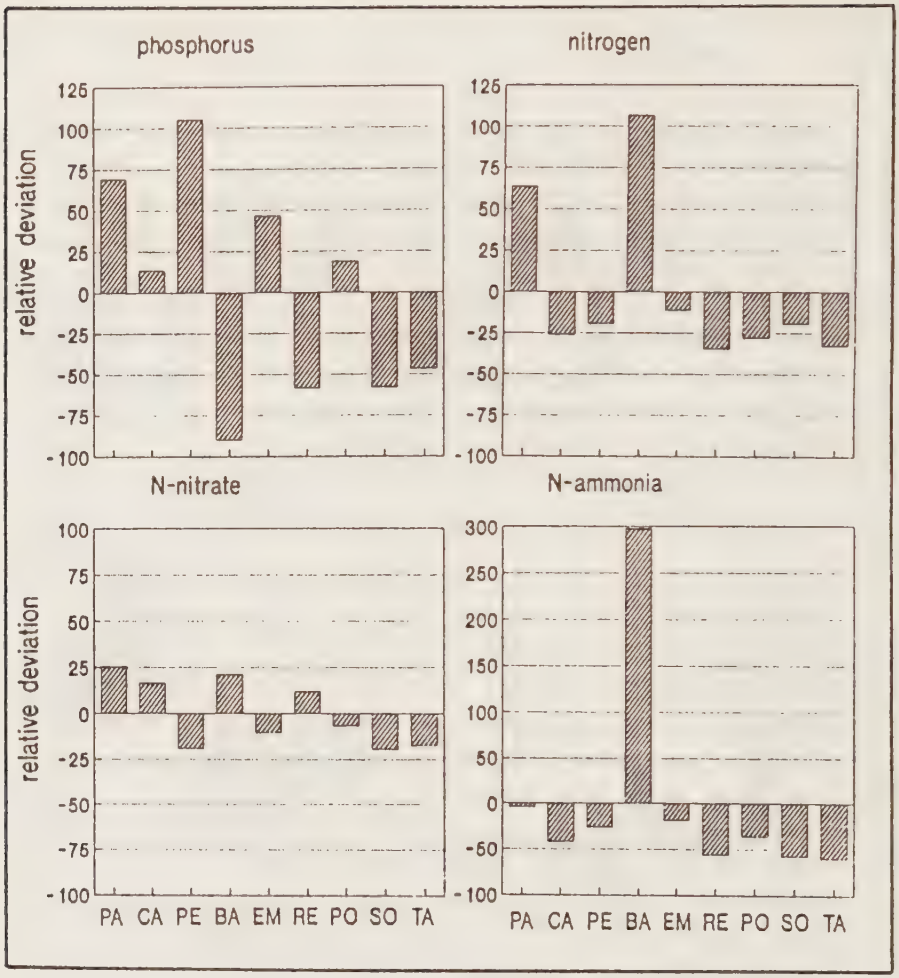


Figure 7: Percent deviation of mean chemical concentrations of water in the littoral zone of selected coastal lakes in Rio Grande do Sul. PA=Palmital Lake; CA=Caieira Lake; PE=Peixoto Lake; BA=Barros Lake; EM=Emboaba Lake; RE=Rincão das Éguas Lake; PO=Porteira Lake; SO=Barros-Solidão Lake; TA=Tarumã Lake.

highlands are introduced in the system through the Guaíba River.

Sulphate showed a slight tendency to decrease from north to south in the coastal gradient, except for values observed in Rincão das Éguas Lake.

Phosphorus appears to be more related to special features of each littoral zone, since different trends among the lakes were depicted. Although relatively close to each other, Peixoto Lake, located at the proximities to a town, showed the highest phosphorus values, whereas Barros Lake showed the lowest ones. Results obtained for coastal lakes in Rio Grande do Sul are by far higher than values obtained for coastal lakes in Rio de Janeiro (ESTEVES et al., 1984), the littoral zone of Polish lakes (PIECZYNSKA, 1972) and Saco de Tapes (this work).

The tendency delineated by chloride contents among the littoral zone is clearly seen in a north-south gradient. All selected lakes located on the north portion of the Coastal Plain presented the lowest chloride values, contrasting with lakes located on the south.

SEDIMENTS

Heavy Metals

Metals are present in sediments in many chemical forms that differ greatly in their bioavailability. Metals in solution, in interstitial or surface waters, or weakly adsorbed to mineral or organic colloids, are considered readly available to biota. Nevertheless, metals in sediments have to be interpreted according to a number of geologic, mineralogic, hydrologic and biologic processes controlled both by internal and external factors (FÖRSTNER & WITTMANN, 1981).

SALOMONS & FÖRSTNER (1984) have pointed out that sediments with a relatively similar grain size conditions can show significant variations in the metal contents. Regarding the influence of grain size in the survey and monitoring of metal pollution in rivers, SALOMONS & FÖRSTNER (1984) stated that once larger sediments fractions are less affected by transport, they may reflect anthropogenic effect on heavy metals distribution. Nevertheless, only a small part of metals in river sediments is bioavailable. The authors also refer the constancy of copper and zinc with sediment depth to silicate fractions. A positive correlation between both heavy metals I have found in thirteen lakes of the Coastal Plain ($r=0.688$; $P<0.01$) (Table 7). Nevertheless, in the sediments taken in Saco de Tapes this relationship changes according to the edge and season. At the eastern margin in summer no correlation was observed, whereas in winter ($r=0.839$; $P<0.001$) and in spring ($r=0.897$; $P<0.001$) a statistically significant positive correlation was obtained. On the other hand, such correlation was found at the northeastern edge only in autumn ($r=0.729$; $P<0.05$) and at the western edge only

Table 7: Simple correlation coefficients relating element concentrations in sediment cores (up to 22 cm depth) of thirteen coastal lakes. Levels of significance for P<0.01 (*) and P<0.001 (**) are given.

	P	N	Ca	Mg	Na	K	Zn	Cu	Cd	Pb
P	1.00									
N	.641*	1.00								
Ca	.335	.915**	1.00							
Mg	.235	.879**	.983**	1.00						
Na	.234	.874**	.982**	.999**	1.00					
K	.817**	.639*	.308	.257	.240	1.00				
Zn	.865**	.777**	.472	.416	.403	.956**	1.00			
Cu	.546	.924**	.866**	.852**	.841**	.595	.688*	1.00		
Cd	.149	.178	.337	.299	.318	-.172	-.132	.165	1.00	
Pb	.315	-.036	-.043	-.181	-.164	.036	.045	-.152	.576	1.00

in winter (r=0.719; P<0.05). In a whole-system analysis, the sediments at the littoral zone of Saco de Tapes showed significant correlation between zinc and copper (r=0.707; P<0.01) (Table 8).

Transport of heavy metal in rivers is likely to depend on different mechanisms. In the Amazon River, copper is transported mainly in detrital crystalline material (GIBBS, 1973). SANCHEZ & LEE (1973) had already observed that the binding capacity of sediments to copper is proportional to the carbonate content of the sediments, but decreases sharply at high excesses of copper. They also noted a release of calcium and magnesium from the sediments at the same time copper is bound to it.

Table 8: Simple correlation coefficients relating element concentrations for a year period in sediment cores (up to 22 cm depth) at nine edges of Saco de Tapes. Levels of significance for P<0.01 (*) and P<0.001 (**) are given.

	P	N	Ca	Mg	Na	K	Zn	Cu	Cd	Pb
P	1.00									
N	.917**	1.00								
Ca	.584	.757*	1.00							
Mg	.394	.576	.547	1.00						
Na	.377	.568	.529	.977**	1.00					
K	.177	.396	.416	.952**	.940**	1.00				
Zn	.380	.528	.537	.919**	.942**	.849**	1.00			
Cu	.661	.857**	.737*	.810*	.770*	.719*	.707*	1.00		
Cd	-.002	-.199	-.232	-.146	-.186	-.297	-.176	-.353	1.00	
Pb	.438	.352	.210	.401	.310	.363	.352	.299	-.221	1.00

Although metals are not homogeneously distributed over sediment fractions, within a grain size spectrum, the clay minerals show relatively high metal contents and the quartz fraction low contents (SALOMONS & FÖRSTNER, 1984; HELIOS-RYBICKA & FÖRSTNER, 1986). Nevertheless, in the coarser fractions the metal content increases (FÖRSTNER, 1982). Therefore, large differences in the metal contents can be observed in sediments collected at a single place.

Metal contents in core samples from Lake Malawi showed a high degree of positive correlation between iron, cobalt, copper, manganese and zinc (FÖRSTNER, 1977). FÖRSTNER stated also that the distribution of minor and trace metals in Lake Malawi sediments was in agreement with changes in redox conditions. In Lake Tupé (Amazônia)

he observed extremely low concentrations of some metals and ascribed it as resulting from the low sorption capacity of kaolinite clay in contact with water having a very low pH.

Redox potential and pH measurements at five sediment cores (27 cm depth), sampled in a transection at the southern edge in Saco de Tapes, showed clearly negative significant correlations ($r=-.706$; $P<0.001$) (Fig. 8). While redox potential decreased with core depth (Fig. 9), pH showed an opposite trend. In a transection performed on the northeast margin, the same tendency was observed ($r=-.424$; $P<0.01$), but sediment cores never showed reduction conditions. Studies carried out in sediments of Lake George (Uganda), on the other hand, showed that mixing zones accounted for divergences of the pH and Eh in the upper layer (VINER, 1975, 1977), but a closer correlation was obtained between both parameters in a 200 cm depth sediment core.

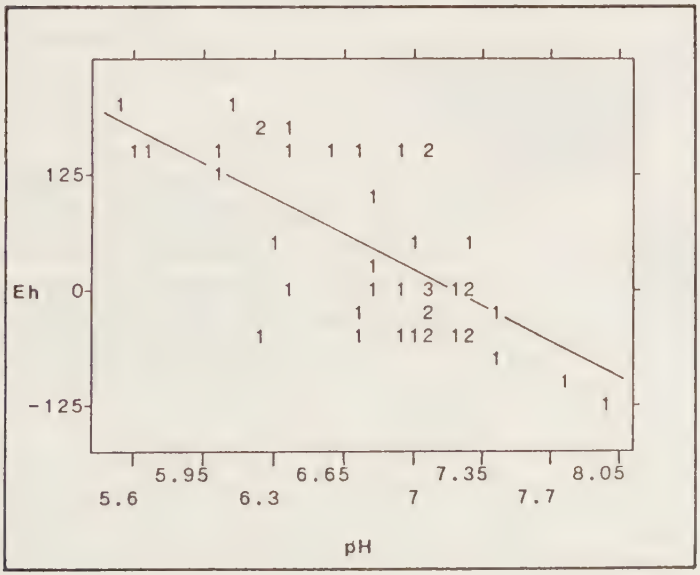


Figure 8: Relationship between sediment Eh (mV) and sediment pH in the southern edge of Saco de Tapes.

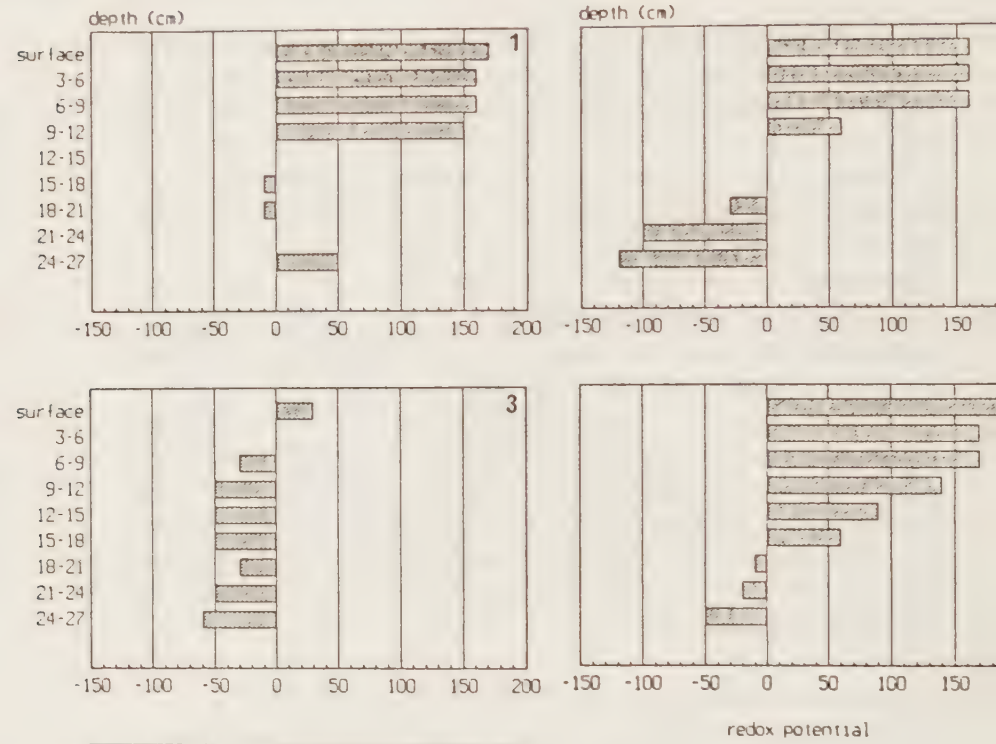


Figure 9: Redox potentia profiles in sediment core from the southern edge o Saco de Tapes. Figures ar disposed in an inshore-ope lake gradient. 1, 2= insid the littoral zone; 3= in the border between bulrush stands and open lake; 4, 5 in the open lake.

The more homogeneous trend, regarding redox potential in a sediment profil, was observed in the border between bulrush stands and open lake (Fig.9.3). At this place sediment erosion takes place since the macrophyte stands act as a barrier to waves. The latter, crossing the littoral zone, reach the shore with least intensity. Resulting from the direct impact of waves in the border of such zones, if shallow, is a local erosion of sediments. By this means, oxygenated layers were only found near the uppermost six centimeters of sediment, whereas redox conditions were observed below this depth. The maintenance of such patterns depends obviously on the organic matter being present in the sediment.

In places where fresh- and salt-water intermix, salinity plays an important role in influencing metal concentrations (FÖRSTNER & WITTMANN, 1981), and flocculation takes place where fluvial sediments encounter the salt water from the sea (SALOMONS & FÖRSTNER, 1984; SALOMONS et al., 1988). In the Saco de Tapes, with increasing salinity due to the entering sea water in the system, a competition between chloride ions and particulates for complexation of the dissolved metals may occur. Studying sediments in such aquatic system, GUERRA (1988) have already mentioned an increase of lead and copper concentrations during winter. On the other hand, in the Patos Lagoon estuary, cadmium in the sediments appears with high concentrations (BAISCH et al., 1988). The influence of water chlorinity is extremely drastic for cadmium since strong complexation occurs at all pH values, and an increase in chlorinity is followed by a decrease in adsorption to the suspended matter. Nevertheless, the relation between suspended matter and chlorinity depends on hydrodynamic conditions (BAPTISTA, 1986; SALOMONS et al., 1988). In the Patos Lagoon estuary, with the entrance of salt water, it is

likely that a complexation of cadmium with chloride ions takes place. Furthermore, if salt water reaches the south portion of Saco de Tapes, the flocculation may occur, and even more dissolved metals may be removed from solution. With increase in residence time, the metals are more attached to the sediments and are less subject to desorption (SALOMONS et al., 1988).

Based on other studies relating adsorption/ desorption processes occurring in estuaries, SALOMONS et al. (1988) listed some of the effects which may cause this phenomena:

- oxidation of organic particles containing trace metals or of metal sulphides, and the desorption caused by high dilution ratio;
- increase in chlorinity causing a competition between chloride ions and particulates for complexation of the dissolved metals;
- changes in turbidity which promote additional sites for adsorption;
- changes in pH which affect adsorption-desorption processes;
- formation of new particulate matter, as hydroxides, and release of dissolved organic matter from the pore water; and
- flocculation of dissolved organic matter and changes in estuarine particles surface properties.

Concentrations of heavy metals are generally higher in soft deposits that characterize areas of accumulation where fine materials are continuously deposited (HÅKANSON, 1988). HÅKANSON also characterized areas of transportation and erosion. The former prevails where fine materials are periodically deposited, whereas the latter constitutes areas with no defined deposition as bottoms of sand, gravel and rocks. In Saco de Tapes fine

grain sediments, as well as organic material, deposit mainly near the east margin (GUERRA, 1988), but some accumulation areas are also found in the west side, near the town of Tapes.

The depth gradient depicted by cadmium levels in the sediments in the eastern edge, in summer (Fig. 10),reveals that this heavy metal may be more related to fine grain sediments, since no correlation was obtained with organic matter content ($P>0.10$). Although cadmium levels were higher in summer, almost the same depth gradient was observed in winter (Fig. 11). Lead accumulated in the uppermost six centimeters sediment in summer, whereas in winter two peaks were observed: the first near the superficial sediment layer and the second at the rhizome zone, between 10 and 14 centimeters depth. Although copper in winter was relatively higher than in summer, a similar accumulation pattern was observed through a depth gradient. Two peaks of copper accumulations were observed in both seasons: the first above the rhizome zone (between 4 and 6 centimeters depth) and the second in the rhizome zone itself. Zinc in summer showed high values in the uppermost four centimeters sediment and in the rhizome layer. Nevertheless, in winter no special trend was observed. In soil profile total zinc normally remains constant, but extractable zinc drops sharply with depth (COLLINS, 1981). In a general manner, copper and zinc showed different trends of accumulation in the superficial sediment layer in the eastern margin in Saco de Tapes. The former was higher in summer and the latter in winter.

During winter, the western margin appears with a relatively continuous heavy metal levels in the sediment core (Fig. 12), whereas the eastern margin remains with the typically unpolluted sediment features (Fig. 11). Cadmium in the western edge presented very low levels but

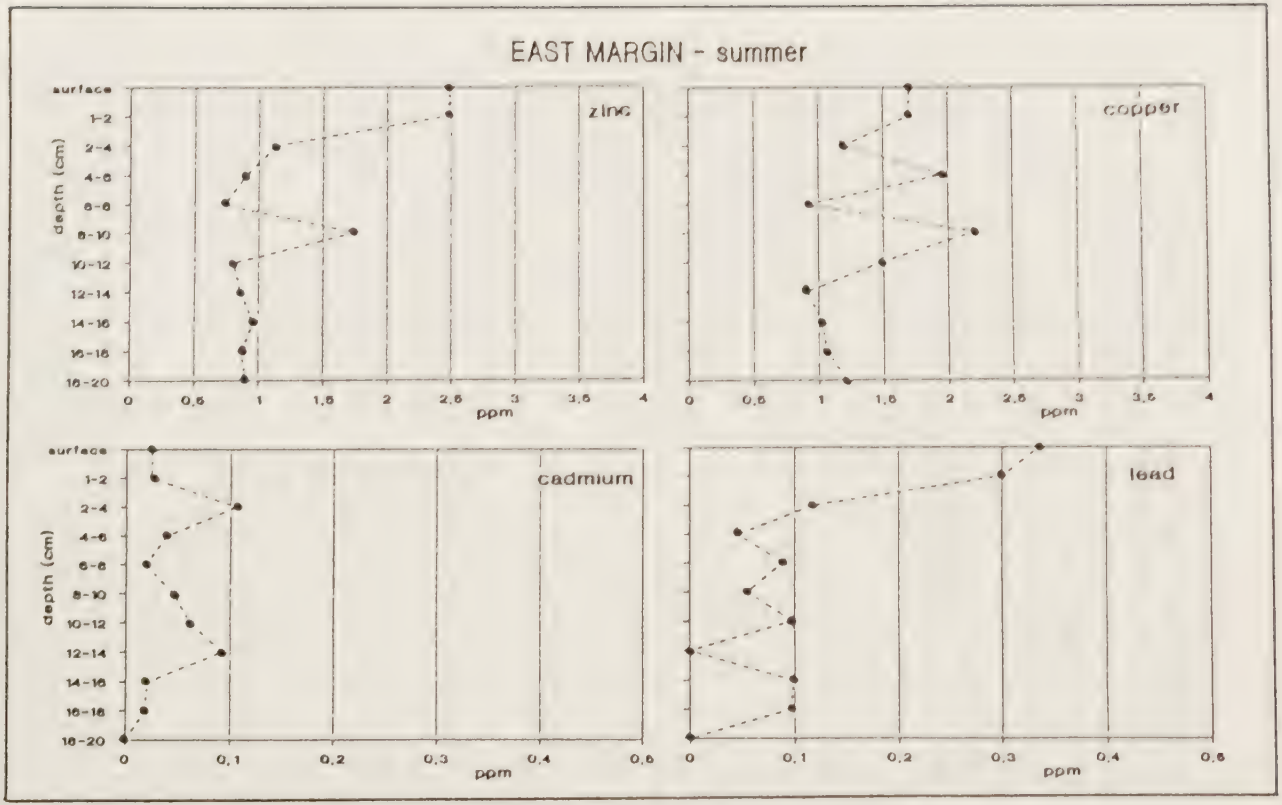


Figure 10: Distribution of zinc, copper, cadmium and lead concentrations in sediment core of Saco de Tapes (east margin).

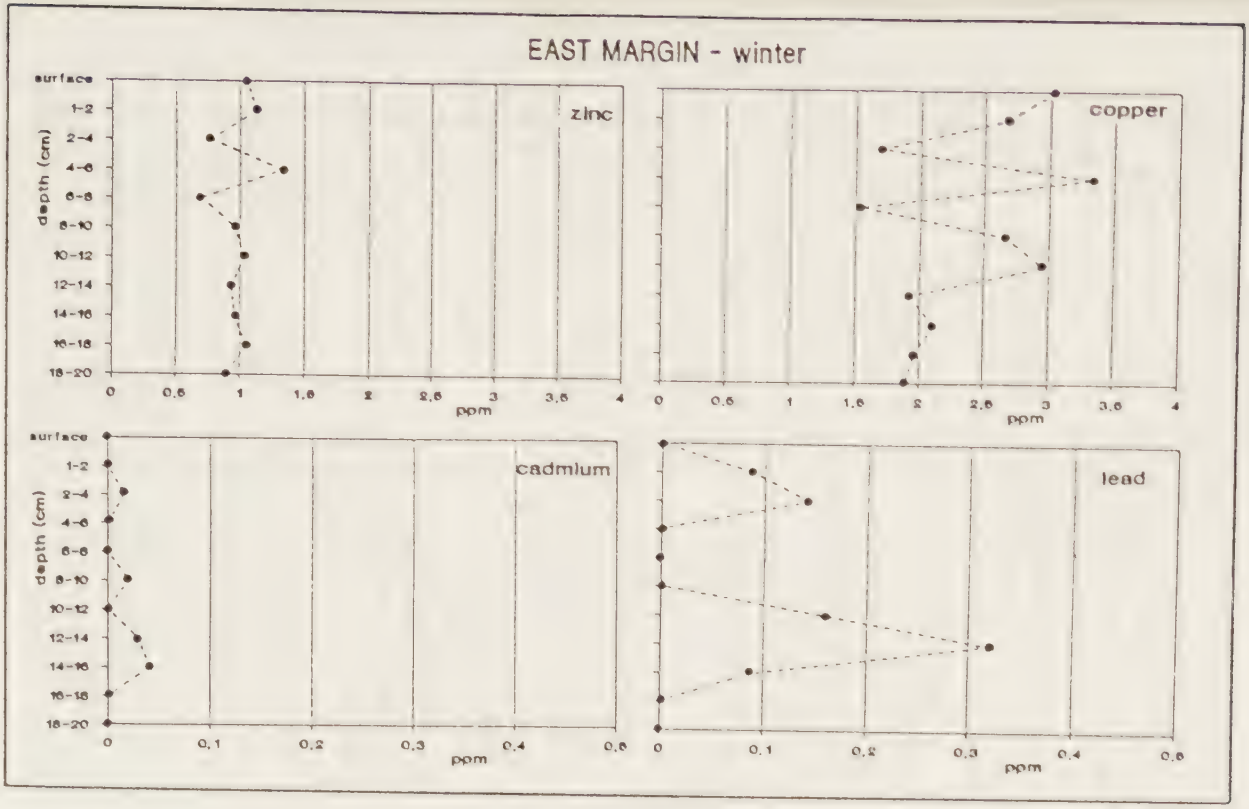


Figure 11: Distribution of zinc, copper, cadmium and lead concentrations in sediment core of Saco de Tapes (east margin).

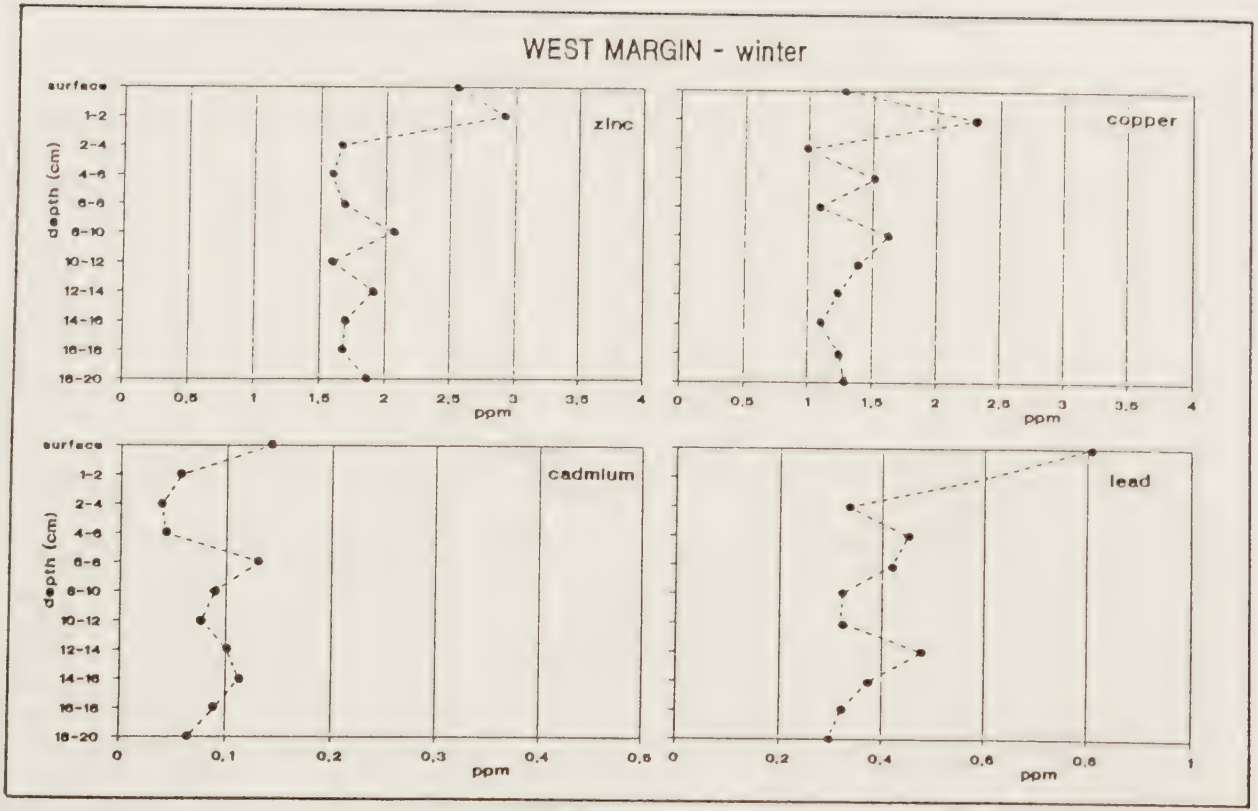


Figure 12: Distribution of zinc, copper, camdium and lead in sediment core of the west margin (Saco de Tapes).

showed a tendency to increase in the superficial layer and in the rhizome zone. However, such values were higher than those found in the opposite margin, in the same period. Lead appeared with high levels in the uppermost sediment layer and a slight increase was noted above and in the rhizome zone. Although occurring in different proportions, both heavy metals showed the same trend in a depth gradient. Zinc and copper also presented the same trends, although the former was slightly higher.

In Sepetiba Bay (Rio de Janeiro), LIMA et al. (1986) have shown that higher mean concentrations of zinc and cadmium occur mainly in the uppermost 17 centimeters sediment depth, that comprise the sediment zone above the *S.alterniflora* roots system. In a sediment core (up to 40 centimeters depth) analysed in the southern margin of Saco de Tapes, during winter, zinc showed a peak of accumulation in the rhizome layer and below the roots zone (e.g. between 32 and 36 centimeters depth), whereas cadmium showed a typical trend of unpolluted areas (Fig. 13). Nevertheless, although lead showed high values in the superficial sediments, no correlation was obtained between this element and depth or even organic matter ($P>0.10$). Furthermore, an upward concentration gradient of heavy metals may indicate that biochemical factors, as well as biological activity in the upper sediment core occur (CLINE & CHAMBERS, 1977). The sedimentation of particulate matter (HART, 1982) and release processes (SALOMONS et al., 1988) are also important mechanisms in concentrating heavy metals in superficial sediments. Zinc and copper showed high levels in the southern edge during winter, compared to the western site. However, copper in the eastern margin was slightly higher. A marked difference between lead and cadmium values was detected in the sediment core of the littoral zone in the southern margin. Lead was extremely high in the superficial layer

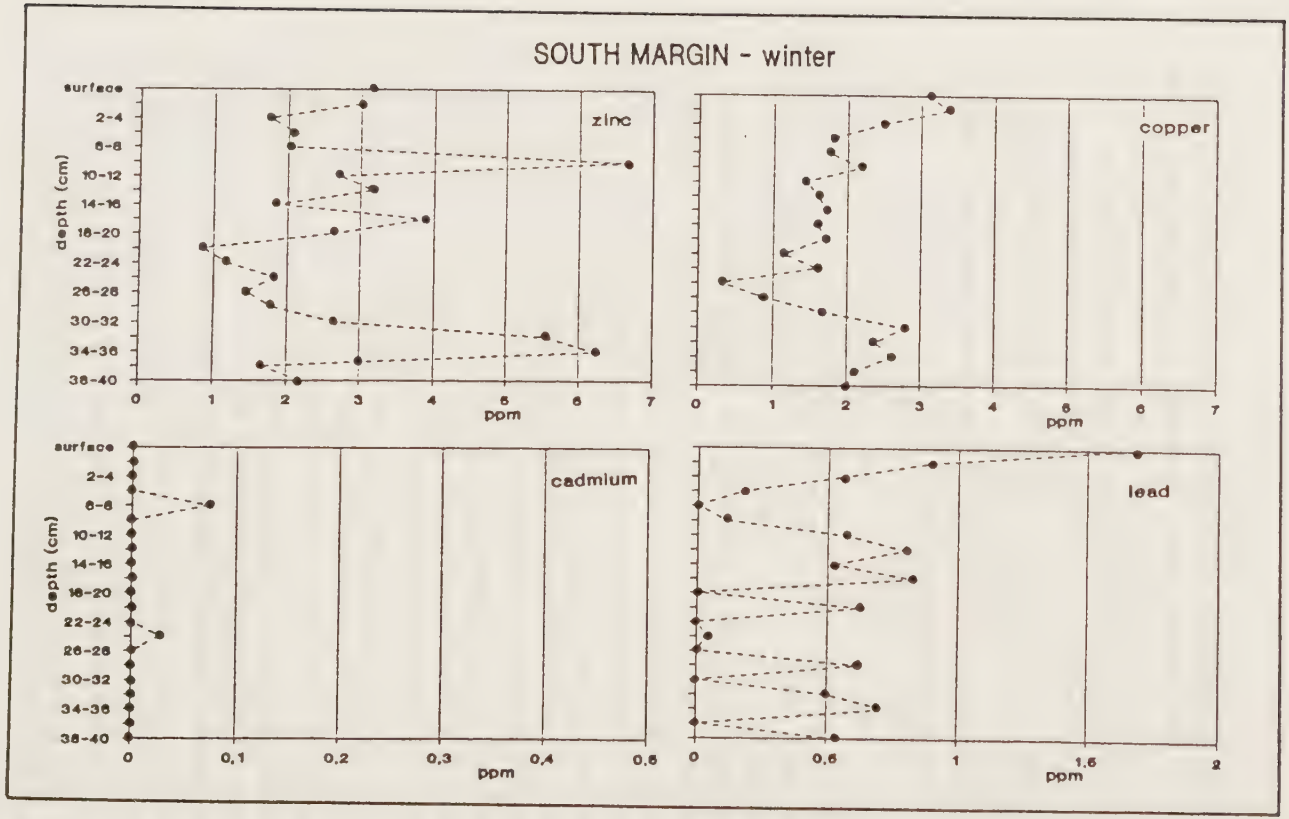


Figure 13: Distribution of zinc, copper, cadmium and lead concentrations in sediment core of the south margin (Saco de Tapes).

whereas cadmium showed only small amounts between 6 and 8, and 24 and 26 centimeters depth. As cadmium settlement is likely to occur with suspended particles being present in the water column, probably such mechanism is effective only after the normal water level in the system is re-established. Such observations are in agreement with data obtained in a sediment core during summer (Fig. 14), when a heavy metal enhancement was noted in the uppermost sediment layers.

The background concentrations of heavy metals in some lacustrine sediments listed by SALOMONS & FÖRSTNER (1984) are by far higher than the levels found in Saco de Tapes. However, in some sediment cores of the coastal lakes cadmium appears with slightly higher values. On the other hand, it may be taken into account that pre-established background levels vary according to the geographical position of the lake, the geology of the lake basin, the suspended material being present in the water, the grain size and type of sediment, the accumulation zones (highly dependent on wind direction), and seasonality of lake parameters. For instance, it can be pointed out that the background levels cited to lacustrine sediments by SALOMONS & FÖRSTNER (1984) are not useful for the interpretation and comparison of the heavy metal levels measured in the sediments of lakes in the Coastal Plain of Rio Grande do Sul.

Heavy metal distributions in sediment cores of littoral zones in some coastal lakes reflect naturally occurring processes and, in some cases, weak atmospheric inputs are noted (Fig. 15) (Table 9). Analysis performed during summer in the sediments of the littoral zone suggest that only cadmium in Barros-Solidão Lake and lead in Tarumã and Barros-Solidão lakes were lower than those obtained in Saco de Tapes, in the same period.

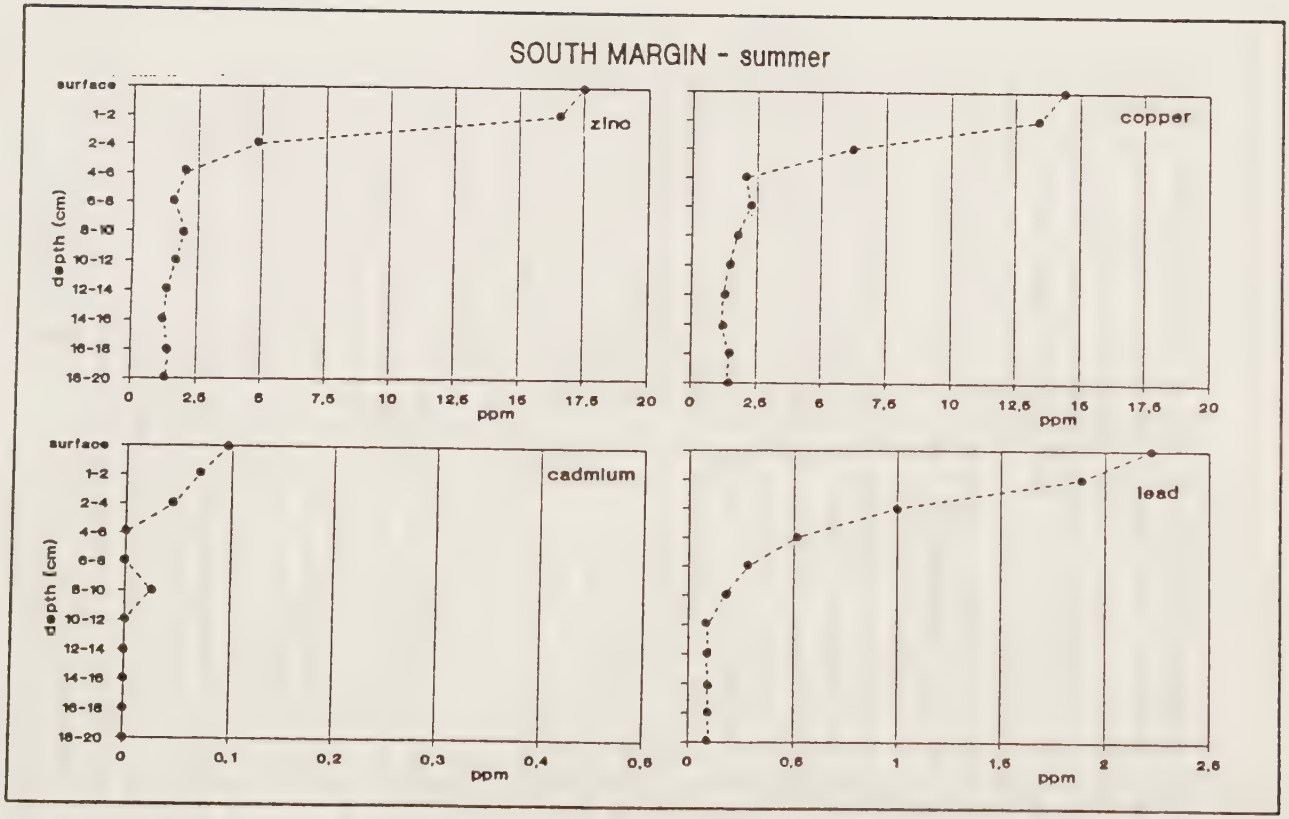


Figure 14: Distribution of zinc, copper, cadmium and lead concentrations in sediment core of the south margin (Saco de Tapes).

Table 9: Heavy metal contents (ppm) in sediment cores of the littoral zone in selected coastal lakes. Means and standard deviations are based on triplicate determinations. To each lake n=33.

lake	Zn	Cu	Cd	Pb
Palmital	0.87(0.28)	1.38(0.94)	0.03(0.06)	0.45(0.48)
Caieira	0.97(0.59)	1.36(1.02)	0.17(0.27)	1.63(2.29)
Peixoto	0.81(0.53)	1.44(1.09)	0.19(0.22)	0.67(1.50)
Barros	0.72(0.27)	1.15(0.56)	0.06(0.08)	0.18(0.25)
Emboaba	1.07(1.21)	0.90(0.33)	0.14(0.19)	1.55(2.17)
R.Éguas	0.99(0.34)	0.97(0.83)	0.04(0.06)	0.32(0.35)
Porteira	1.53(1.00)	2.75(1.43)	0.20(0.12)	0.24(0.14)
B.Solidão	0.42(0.24)	0.84(0.39)	0.02(0.03)	0.06(0.06)
Tarumã	0.48(0.29)	1.38(0.75)	0.08(0.14)	0.03(0.04)

Figure 15: Spatial distribution of zinc, copper, cadmium and lead concentrations in littoral sediments of some selected coastal lakes (cores up to 20 centimeters depth).

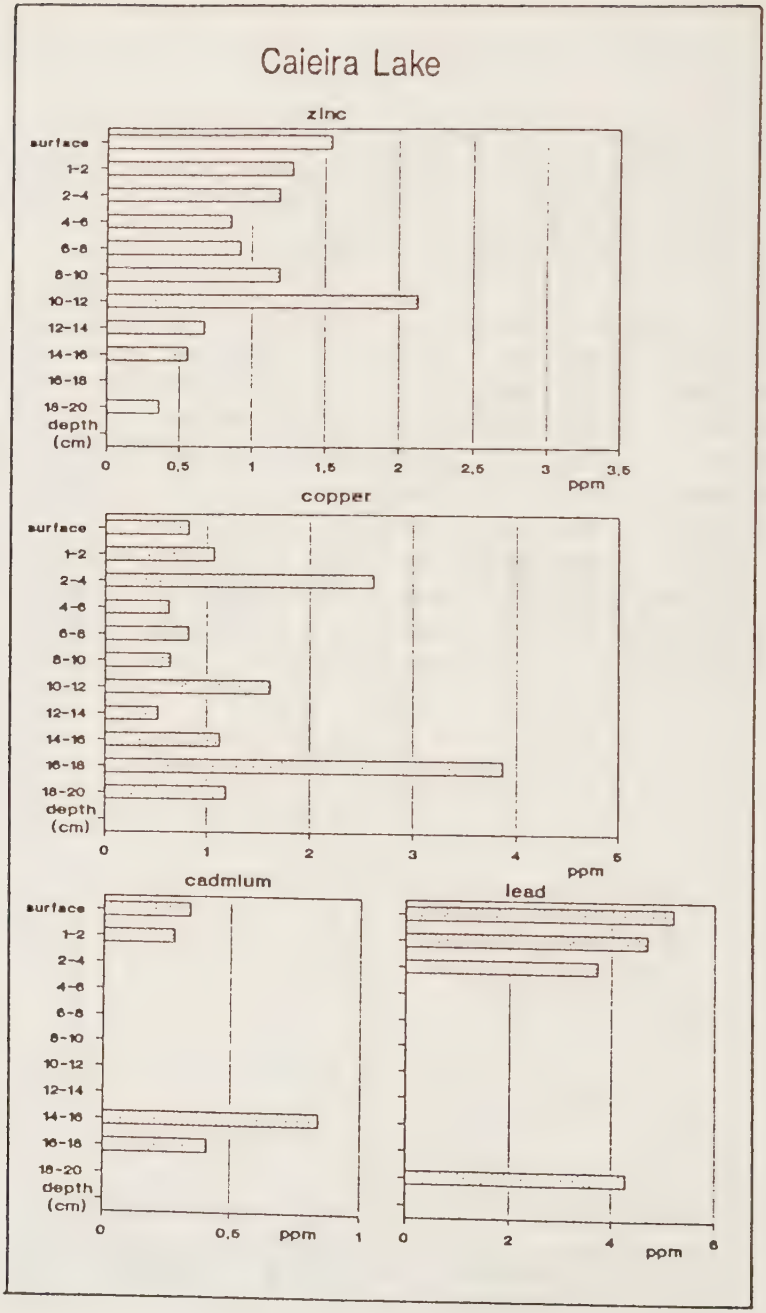

Caieira Lake
zinc
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
0,5
1
1,5
2
2,5
3
3,5
ppm
copper
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
1
2
3
4
5
ppm
cadmium
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
0,5
ppm
1
lead
0
2
4
ppm
6

Fig.15

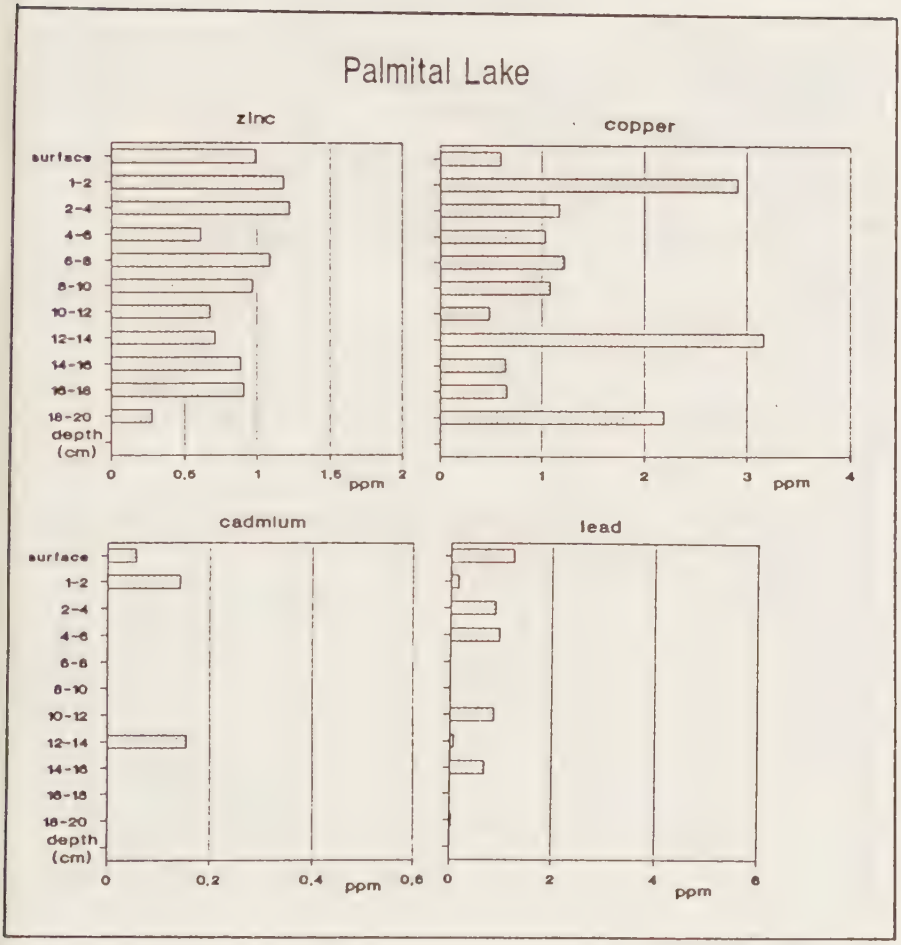

Palmital Lake
zinc
copper
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth
(cm)
0
0,5
1
1,5
2
ppm
0
1
2
3
4
ppm
cadmium
lead
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth
(cm)
0
0,2
0,4
0,6
ppm
0
2
4
6
ppm

Fig.15

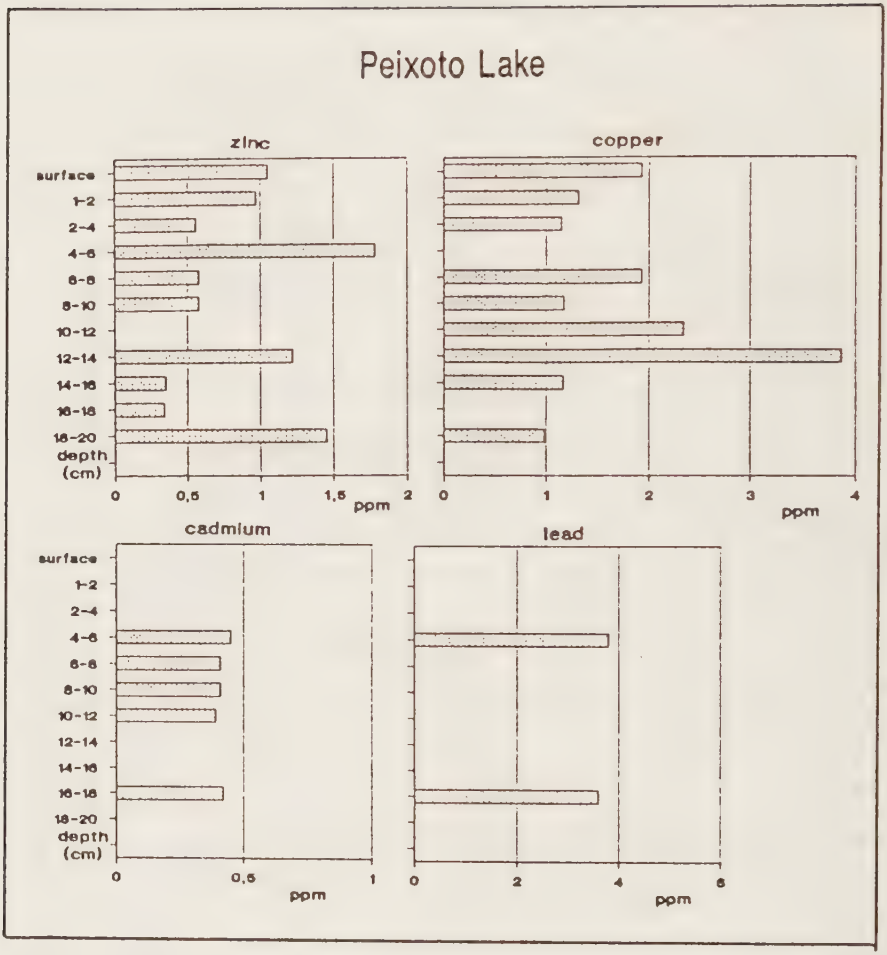

Peixoto Lake
zinc
copper
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth
(cm)
0
0,5
1
1,5
2
ppm
0
1
2
3
4
ppm
cadmium
lead
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth
(cm)
0
0,5
1
ppm
0
2
4
6
ppm

Fig.15

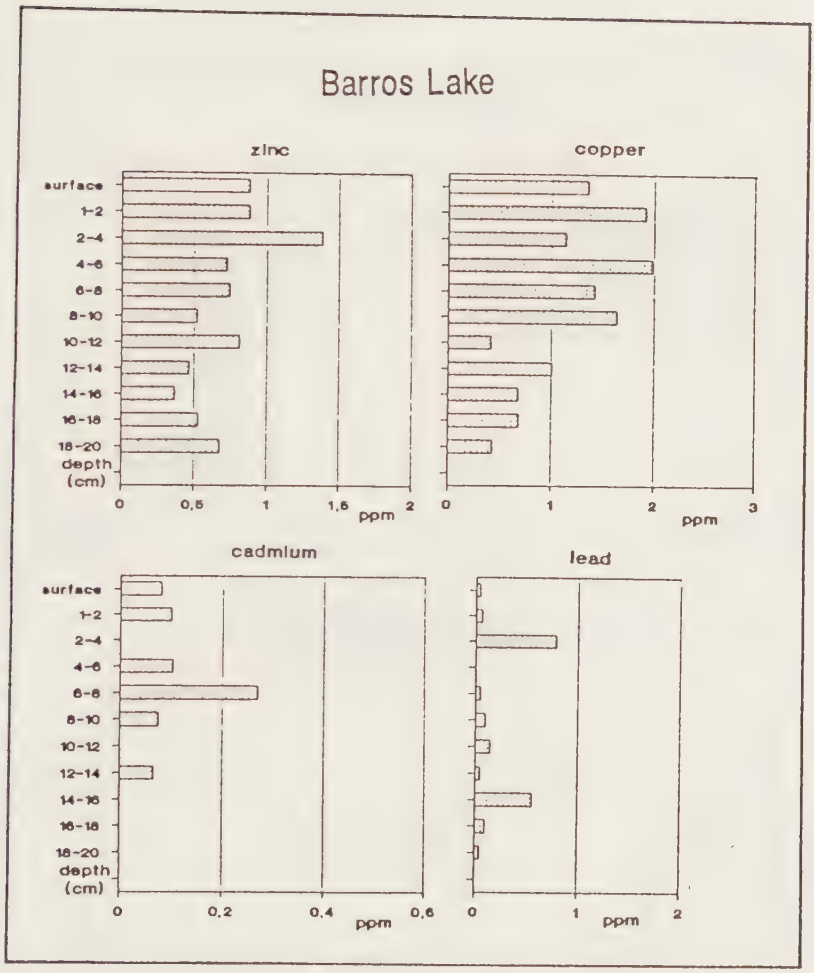

Barros Lake
zinc
copper
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
0,5
1
1,5
2
ppm
0
1
2
3
ppm
cadmium
lead
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
0,2
0,4
0,6
ppm
0
1
2
ppm

Fig.15

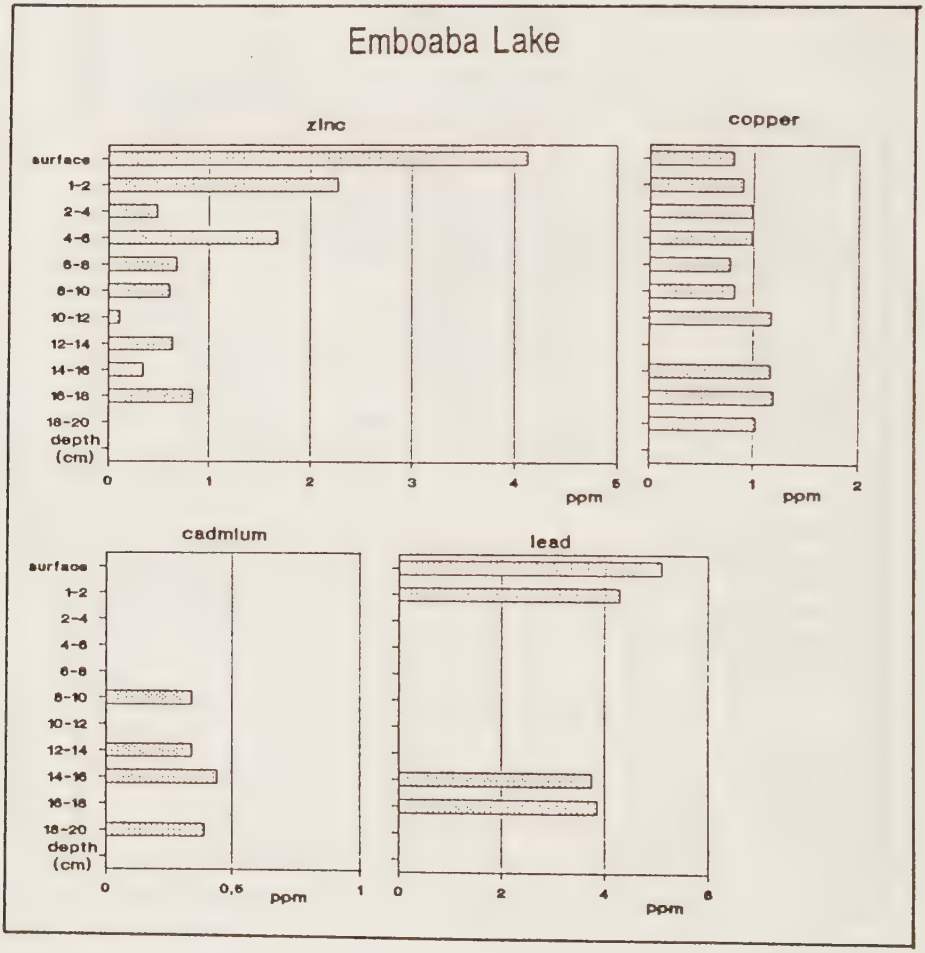

Emboaba Lake
zinc
copper
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
1
2
3
4
5
ppm
0
1
2
ppm
cadmium
lead
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
0,5
1
ppm
0
2
4
6
ppm

Fig.15

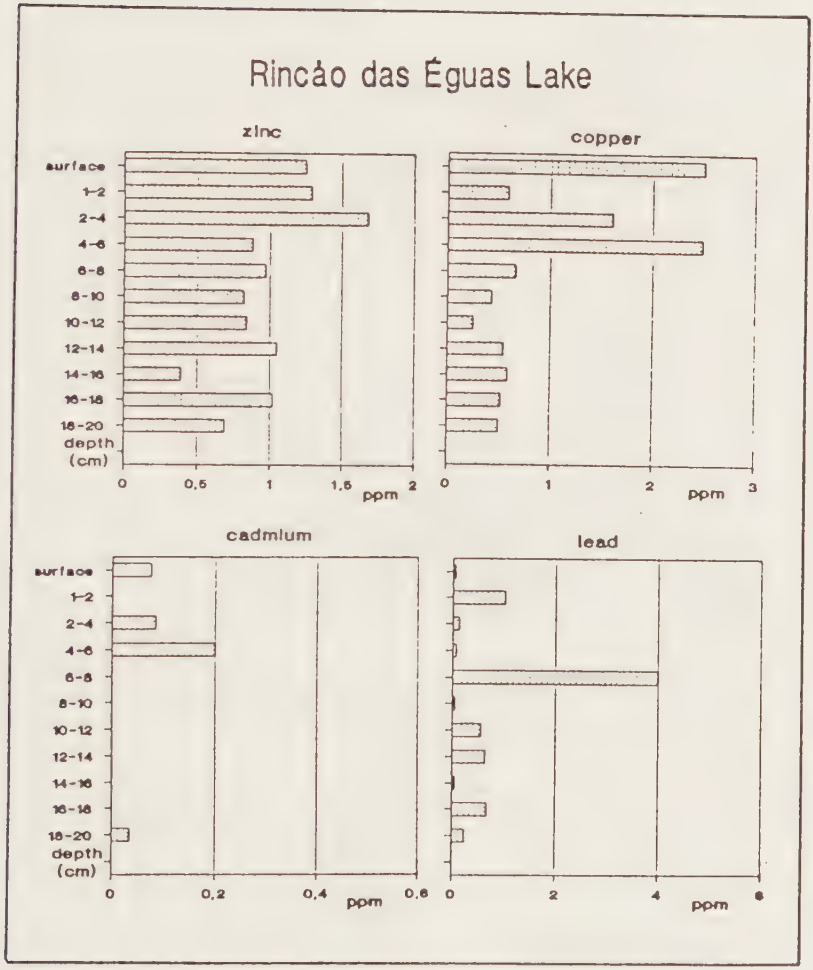

Rincão das Éguas Lake
zinc
copper
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth
(cm)
0
0,5
1
1,5
2
ppm
0
1
2
3
ppm
cadmium
lead
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth
(cm)
0
0,2
0,4
0,6
ppm
0
2
4
6
ppm

Fig.15

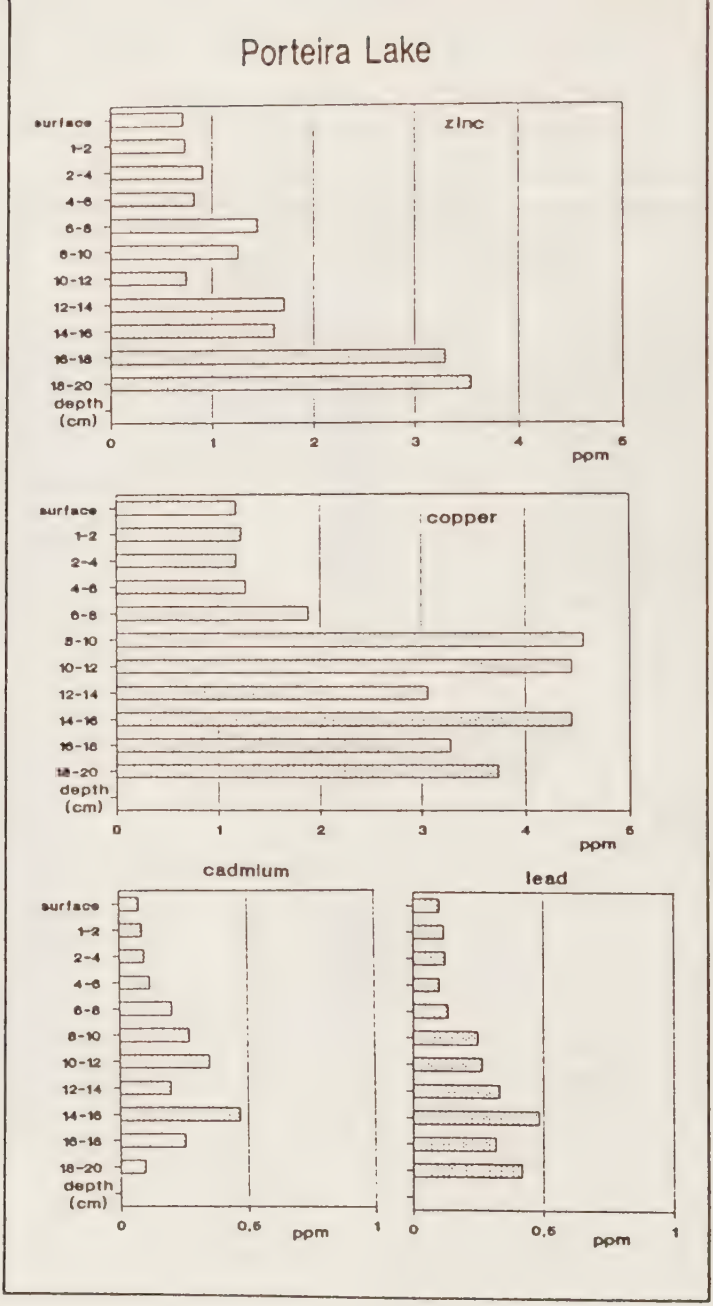

Porteira Lake
zinc
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
1
2
3
4
5
ppm
copper
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
1
2
3
4
5
ppm
cadmium
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
0,5
1
ppm
lead
0
0,5
1
ppm

Fig.15

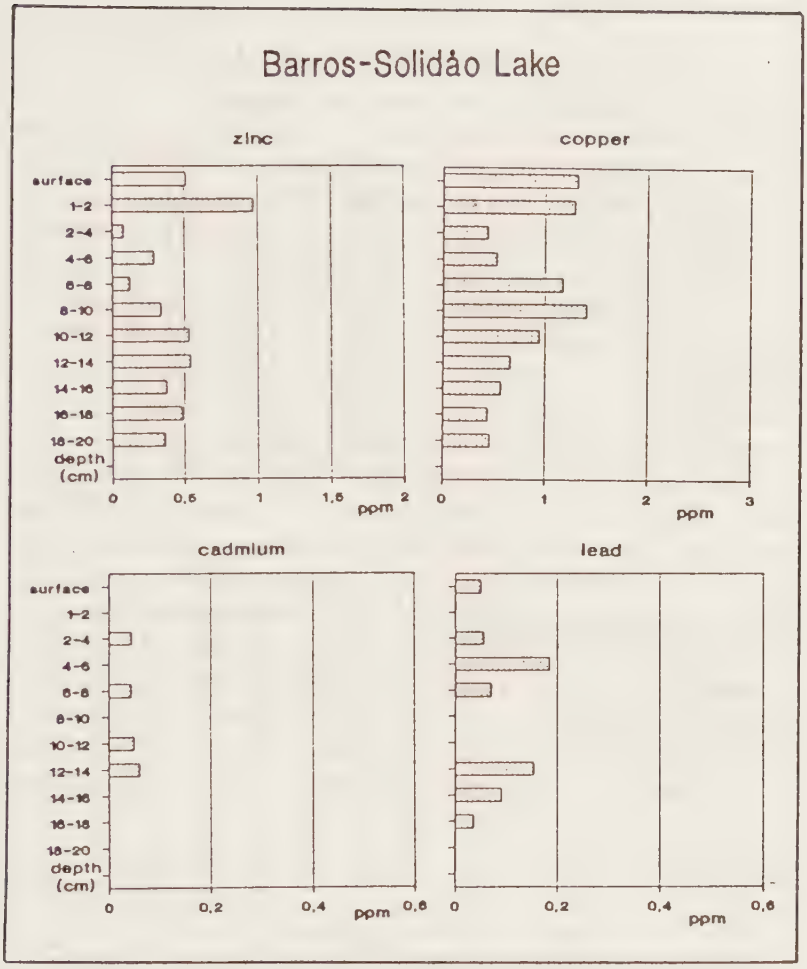

Barros-Solidão Lake
zinc
copper
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
0,5
1
1,5
2
ppm
0
1
2
3
ppm
cadmium
lead
0
0,2
0,4
0,6
ppm

Fig.15

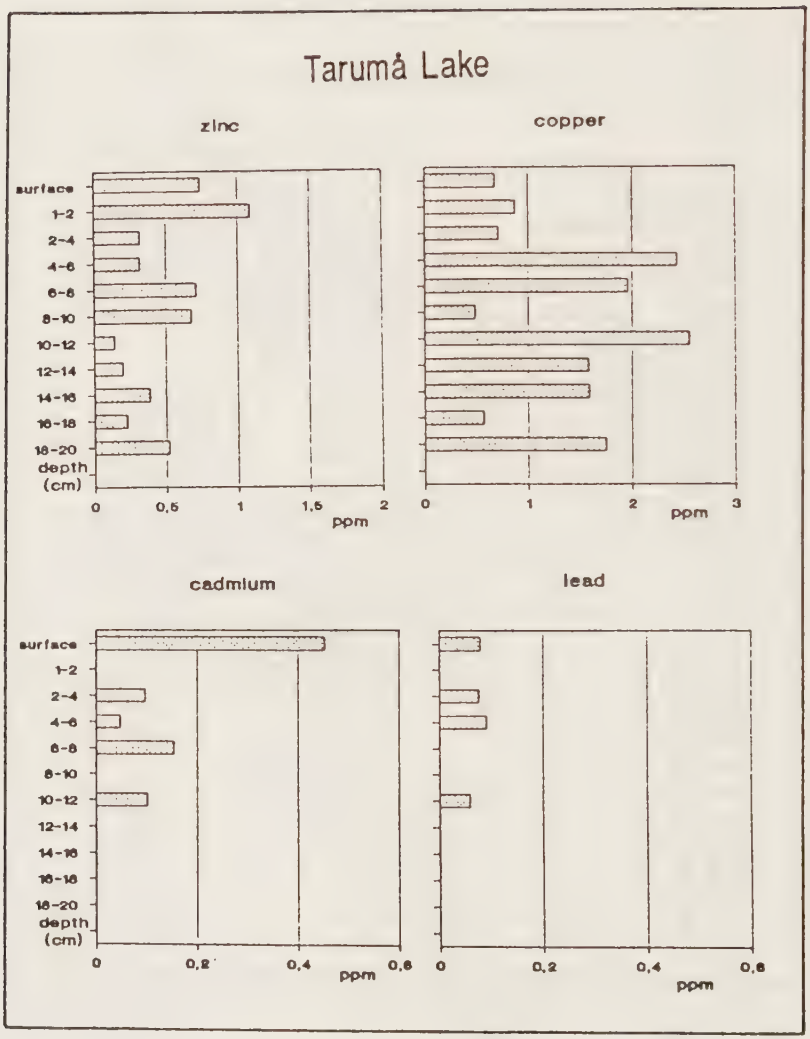

Tarumå Lake
zinc
copper
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
0,5
1
1,5
2
ppm
0
1
2
3
ppm
cadmium
lead
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
0,2
0,4
0,6
ppm
0
0,2
0,4
0,6
ppm

Fig.15

The highest heavy metal accumulations were observed in sediments of Emboaba, Peixoto and Caieira lakes (compare Fig. 15). Such results are primarily dependent on the localization of the lakes, its inputs, and on the sampled littoral zone. Littoral sediments of Emboaba Lake suffer direct inputs promoted by heavy traffic influences, since the lake is located near the main road used to reach the holliday-towns near the beach, during summer periods. The levels showed by lead in sediment strata of Peixoto Lake may result from its proximities to a town and also to the fact that this lake is used during summer as recreational area. Caieira Lake may be influenced by nearly mechanized plantation areas and also by traffic road. It is important to mention that in these coastal regions, the wind direction also plays the important role regarding heavy metal inputs and accumulations.

These results are low if compared to cadmium and lead levels in sediments of eutrophic lakes (MATHIS & KEVERN, 1975) and reservoirs (ESTEVES et al., 1981). Nevertheless, cadmium was slightly higher than the mean concentration mentioned by FÖRSTNER (1977) for the Amazon lakes.

Mineral Elements

Sediment nutrients are likely to determine the growth and biomass distribution of submerged and emergent macrophytes (MISRA, 1938; BARKO & SMART, 1978, 1980, 1981, 1983, 1986; CARIGNAN & KALFF, 1979; DeLAUNE et al., 1979; BARKO, 1982, 1983; SPENCE, 1982; HUEBERT & GORHAM, 1983; SMART & BARKO, 1985). On the other hand, organic matter content in sediments has been recognized as of great interest since macrophytes' composition and distribution are likely to be partially related to that

parameter (SCHIEMER & PROSSER, 1976; BARKO, 1982; ARAUJO DE OLIVEIRA, 1983; BARKO & SMART, 1986).

Nutrient concentrations in the sediment are important factors regarding nutrient cycling and eutrophication in lakes. The exchange of nutrients between sediment and overlying water is extremely dependent on the physical, chemical, and biological processes in lakes. Potential redox and pH (MORTIMER, 1941, 1942; HAYES, 1964; KEMP, 1971; VINER, 1975, 1977; EDZWALD, 1977; DeLAUNE et al., 1981; HOWES et al., 1986; PETTERSSON & BOSTRÖM, 1986), water depth and wave action (BOYD, 1976; KADLEC, 1986), and texture (KEMP, 1971; EDZWALD, 1977; SASAMAL et al., 1986) are factors that should be taken into account when dealing with sediment studies.

Sediments in estuarine zones are subject to an alteration in the mineral concentration due to increasing salinity. In such areas, this factor is known to promote a decrease in inorganic nitrogen uptake by macrophytes (MORRIS,1980). Nevertheless, *Spartina* in salt marsh areas is able to stimulate nitrogen fixation in the sediment and to utilize the fixed nitrogen (JONES, 1974). Influence of salt spray in mineral cycling in coastal regions (CLAYTON, 1972) is marked by a decline in potassium, calcium and magnesium with soil depth.

Changes in the vertical profil of mineral elements were examined in sediment cores of some coastal lakes (Fig. 16). The littoral zone of such lakes is constituted mainly by sandy sediments. Porteira Lake, however, showed more richly organic layers. Due to naturally occurring processes, and to the fact that each lake act, to some extent, as an island to each macrophyte community (according to the lake peculiarities), the nutrient distribution along the sediment profile differed between them. The occurrence of sheltered margins also influences the nutrient gradients since wind action promotes erosion

or mixing of superficial sediments and consequently an alteration in the nutrient profiles. Moreover, a certain type of mixing is also promoted by active sediment burrowers as oligochaetes, chironomids, ostracods and amphipods (VINER, 1977; GRANÉLI, 1979; KAMP-NIELSEN et al., 1982; RIPPEY & JEWSON, 1982; ROBBINS, 1982). For these reasons, nutrient accumulations in superficial sediment layers are probably related to factors that do not reflect directly the trophic state of a lake (FISH & ANDREW, 1980). For such comparisons, core sediment analysis may be a more effective method.

Regarding the coastal lakes in Rio Grande do Sul, relatively high concentrations of phosphorus were observed in Caieira (mean of 24.89 ppm), Peixoto (mean of 42.99 ppm) and Porteira (mean of 46.65 ppm) lakes (Fig. 16) (Table 10). It is very likely that phosphorus levels are associated with organic matter content in sediments. Independent of metabolic uptake, a great phosphate adsorbing capability is shown by organic material in the sediments of tropical lakes and reservoirs (VINER, 1977; ESTEVES, 1983). Nitrogen was extremely high in the uppermost sediment of Caieira Lake (mean of 950.05 ppm), whereas in Porteira Lake, nitrogen presented the highest levels in the rhizome layer, where also sodium increased markedly. Calcium and magnesium showed the same tendency. The highest calcium concentrations, nevertheless, were found in the uppermost sediment of Caieira (mean of 1731.91 ppm) and Emboaba (mean of 801.43 ppm) lakes, and in the whole sediment core of Porteira Lake (mean of 2822.62 ppm) (Fig. 16). On the other hand, mean nutrient concentrations in the littoral zone of lakes in the Coastal Plain are extremely low if compared to values found by ESTEVES (1983) in some tropical reservoirs.

Estimations of potassium in the sediment core were low and not usually detectable, except for Emboaba (in the uppermost 2 centimeters of sediment).

Turbulence effects in the uppermost sediments can imply that such layers are taking part in the nutrient recycling to the lake water (GANF, 1974; VINER, 1977). On the other hand, phosphorus and nitrogen enhancement in superficial sediments can merely result from detrital decomposition in undisturbed sediments (FISH & ANDREW, 1980).

Table 10: Sediment nutrients (ppm) in nine selected coastal lakes. Means and standard deviations are based on triplicate determinations. To each lake n=33.

Lake	P	N	Ca	Mg	Na	K
Palmital	13.39	51.00	77.52	24.04	9.12	0
	(8.67)	(19.11)	(18.62)	(10.30)	(6.05)	-
Caieira	46.65	264.99	575.17	22.03	13.56	0
	(42.74)	(340.19)	(746.58)	(17.82)	(11.48)	-
Peixoto	42.99	128.53	72.72	19.86	18.11	0
	(19.68)	(49.23)	(36.01)	(21.45)	(7.84)	-
Barros	12.87	40.44	116.90	31.38	7.37	2.28
	(7.46)	(38.95)	(124.43)	(29.05)	(7.21)	(7.56)
Emboaba	19.96	117.88	213.09	15.50	17.50	7.47
	(4.66)	(25.76)	(294.07)	(32.01)	(13.56)	(16.65)
R.Eguas	20.72	28.26	32.30	10.35	10.75	0
	(5.36)	(16.43)	(10.67)	(5.33)	(5.13)	-
Porteira	24.89	1113.10	2822.62	1000.01	306.86	0
	(16.16)	(1041.76)	(1686.50)	(478.31)	(168.25)	-
B.Solidão	11.11	33.93	38.92	4.19	5.41	0
	(4.74)	(33.04)	(9.46)	(3.52)	(3.40)	-
Tarumã	11.98	47.46	40.40	21.99	12.60	0
	(4.92)	(52.97)	(17.41)	(6.23)	(5.67)	-

Co-precipitation of phoshate and calcium could be an explanation for the relationship found in the sediment gradients in Caieira ($r=.973$; $P<0.001$), Barros ($r=.910$; $P<0.001$) and Porteira ($r=.709$; $P<0.05$) lakes. However, it is more likely that such relations are due to the nearness of the shore, and the amount of organic matter, than to co-precipitation itself. Furthermore, it appears that for the present chemical conditions in the lakes, phosphorus is more probably associated with iron.

Figure 16: Spatial distribution of phosphorus, nitrogen, calcium, magnesium and sodium concentrations in littoral sediments of some selected coastal lakes (cores up to 20 centimeters depth).

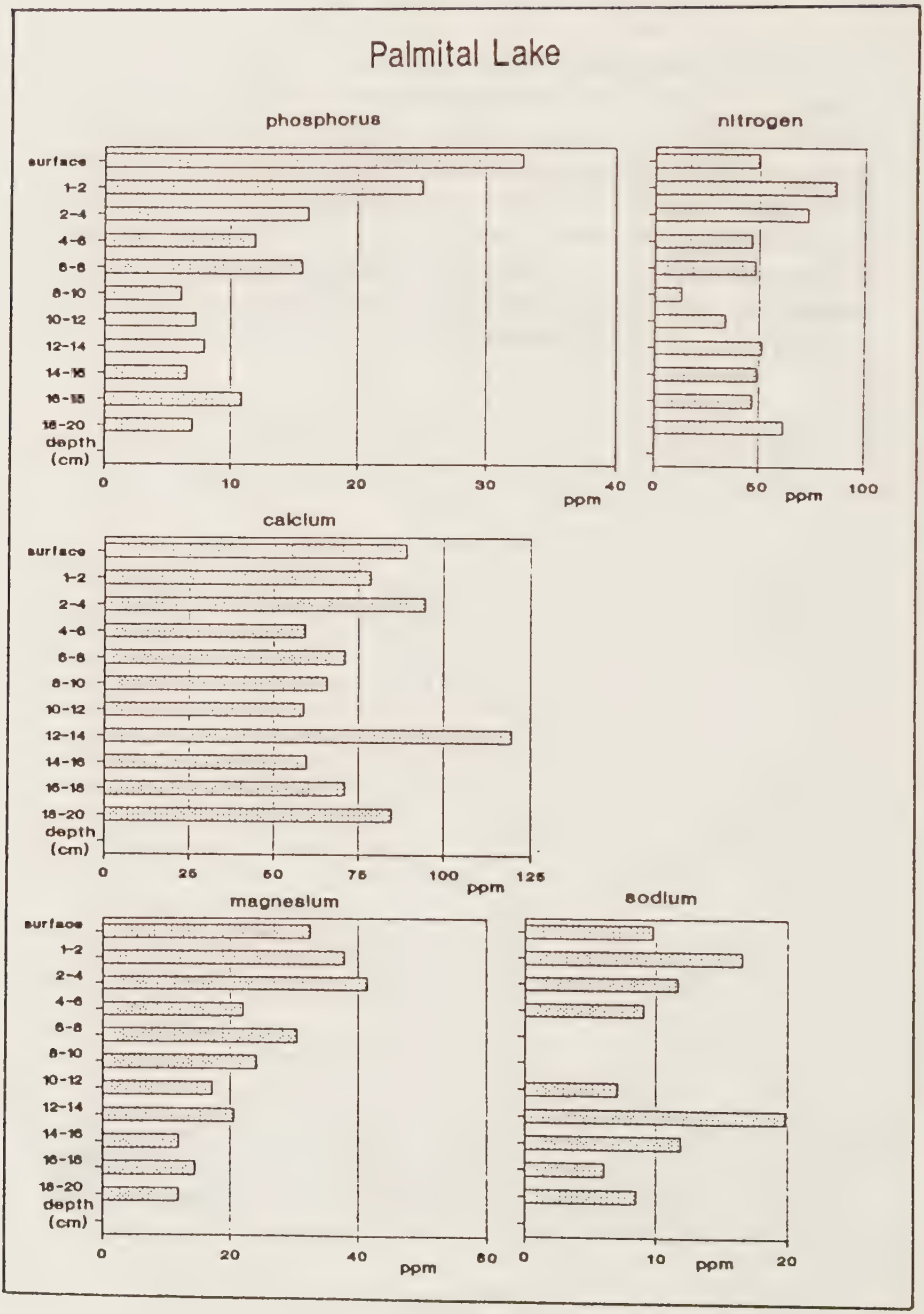
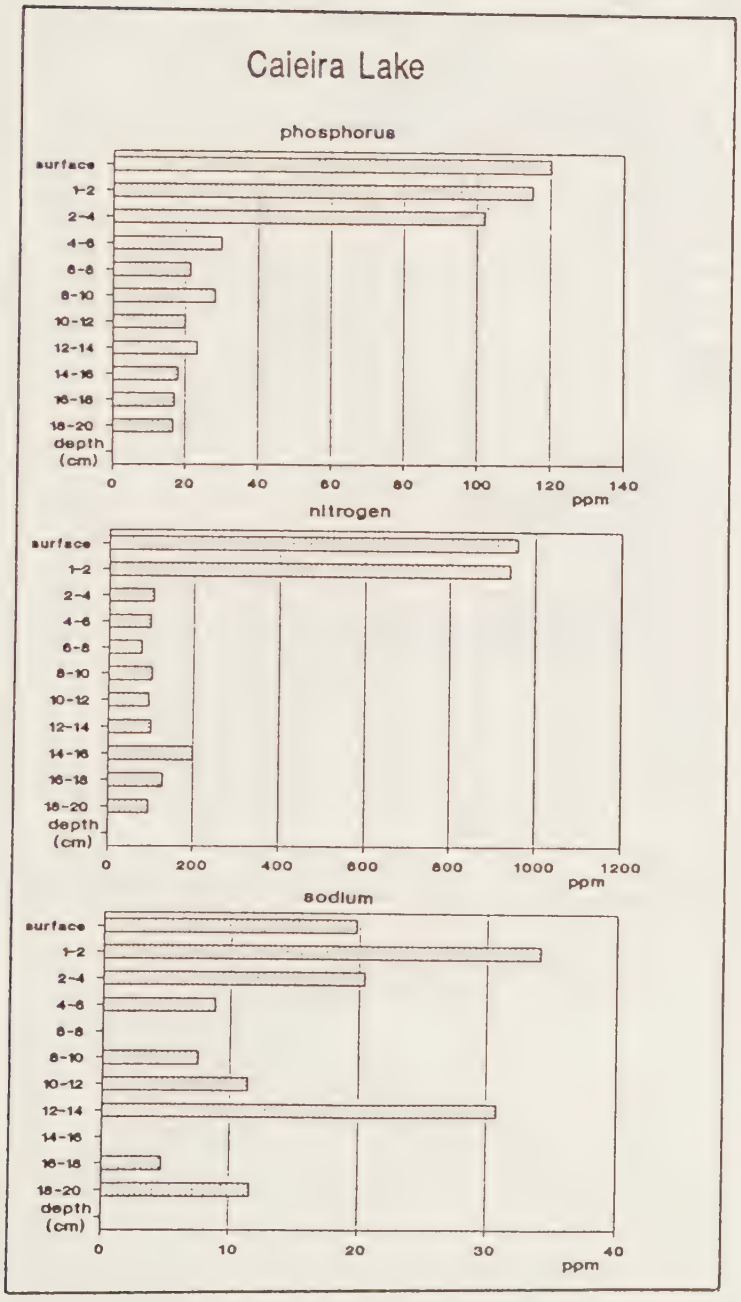

Palmital Lake
phosphorus
nitrogen
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
10
20
30
40
ppm
0
50
100
ppm
calcium
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
25
50
75
100
125
ppm
magnesium
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
20
40
60
ppm
sodium
0
10
20
ppm

Fig.16


Caieira Lake
phosphorus
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
20
40
60
80
100
120
140
ppm
nitrogen
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
200
400
600
800
1000
1200
ppm
sodium
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
10
20
30
40
ppm

Caieira Lake

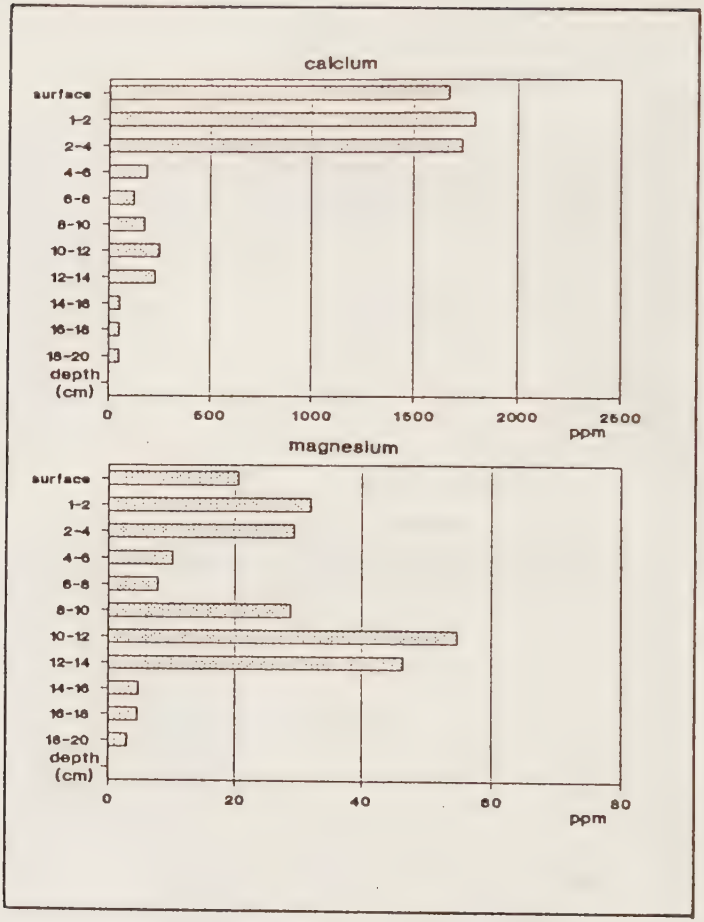
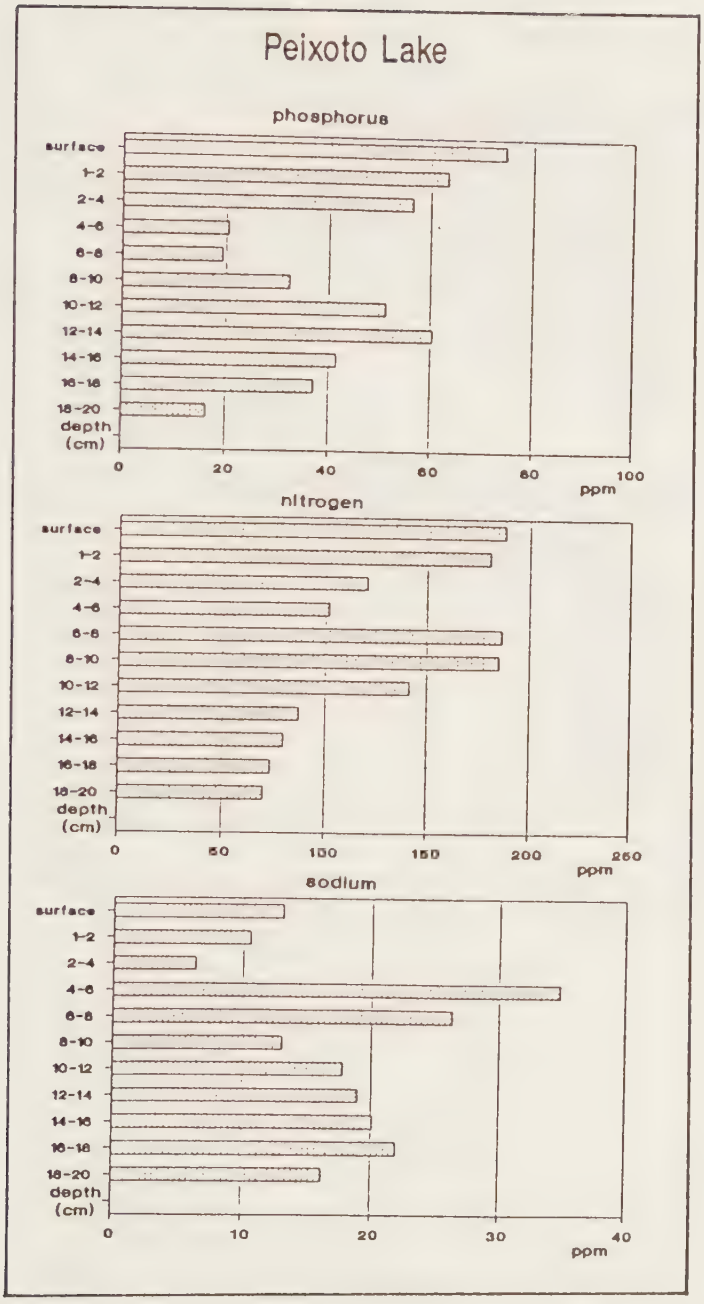


Fig.16


Peixoto Lake
phosphorus
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
20
40
60
80
100
ppm
nitrogen
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
50
100
150
200
250
ppm
sodium
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
10
20
30
40
ppm

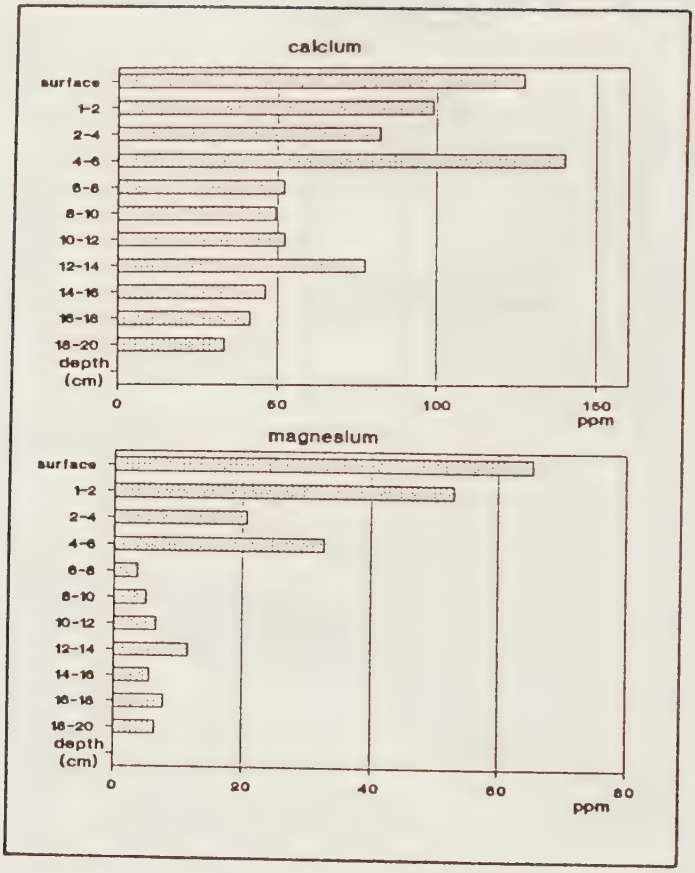
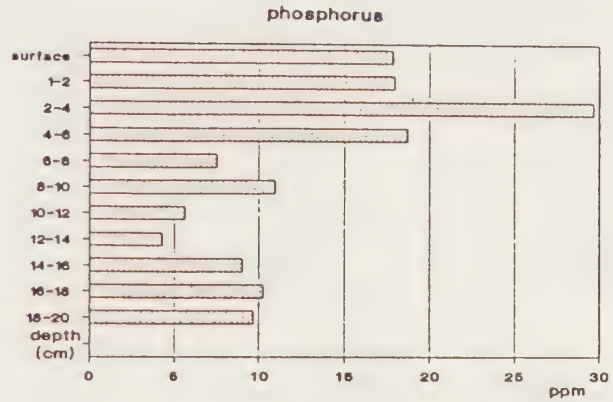
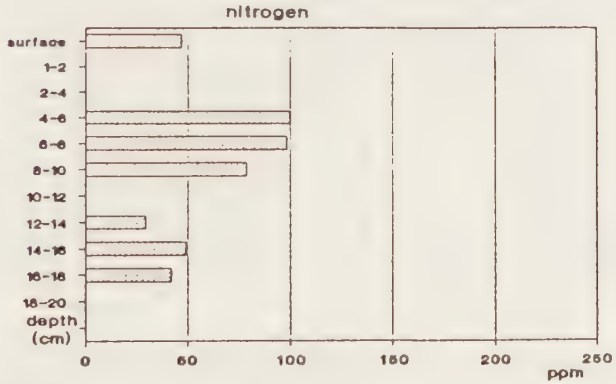
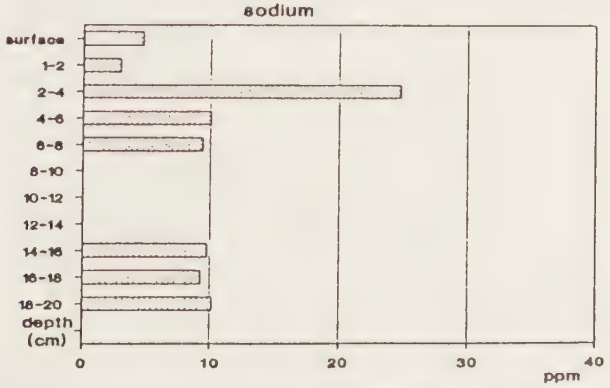

calcium
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
50
100
150
ppm
magnesium
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
20
40
60
80
ppm

Fig.16

Barros Lake


phosphorus
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
5
10
15
20
25
30
ppm


nitrogen
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
50
100
150
200
250
ppm


sodium
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
10
20
30
40
ppm

Barros Lake

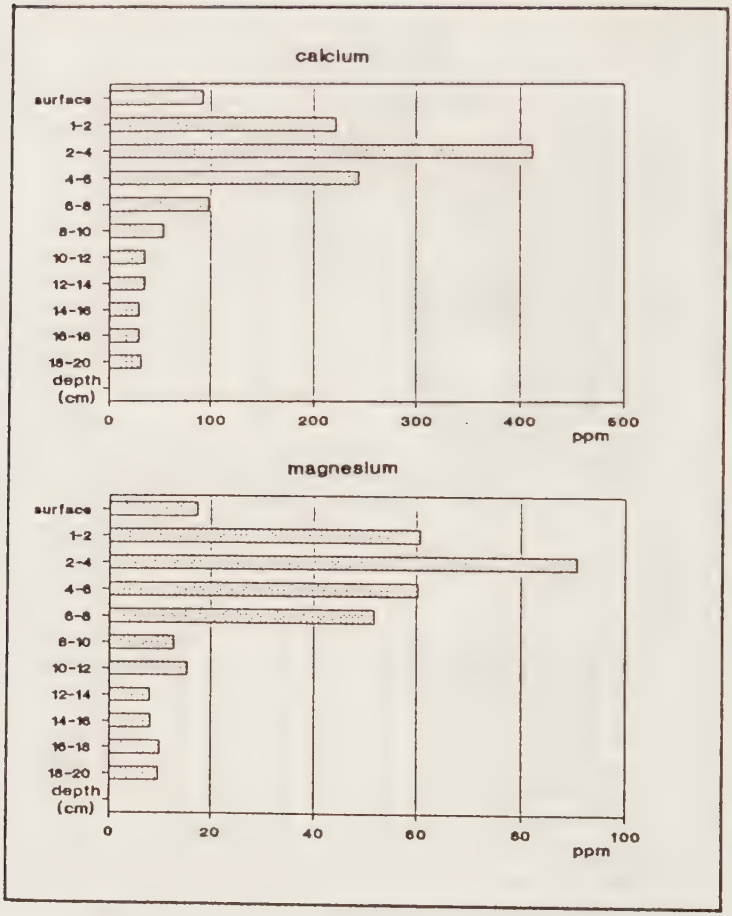
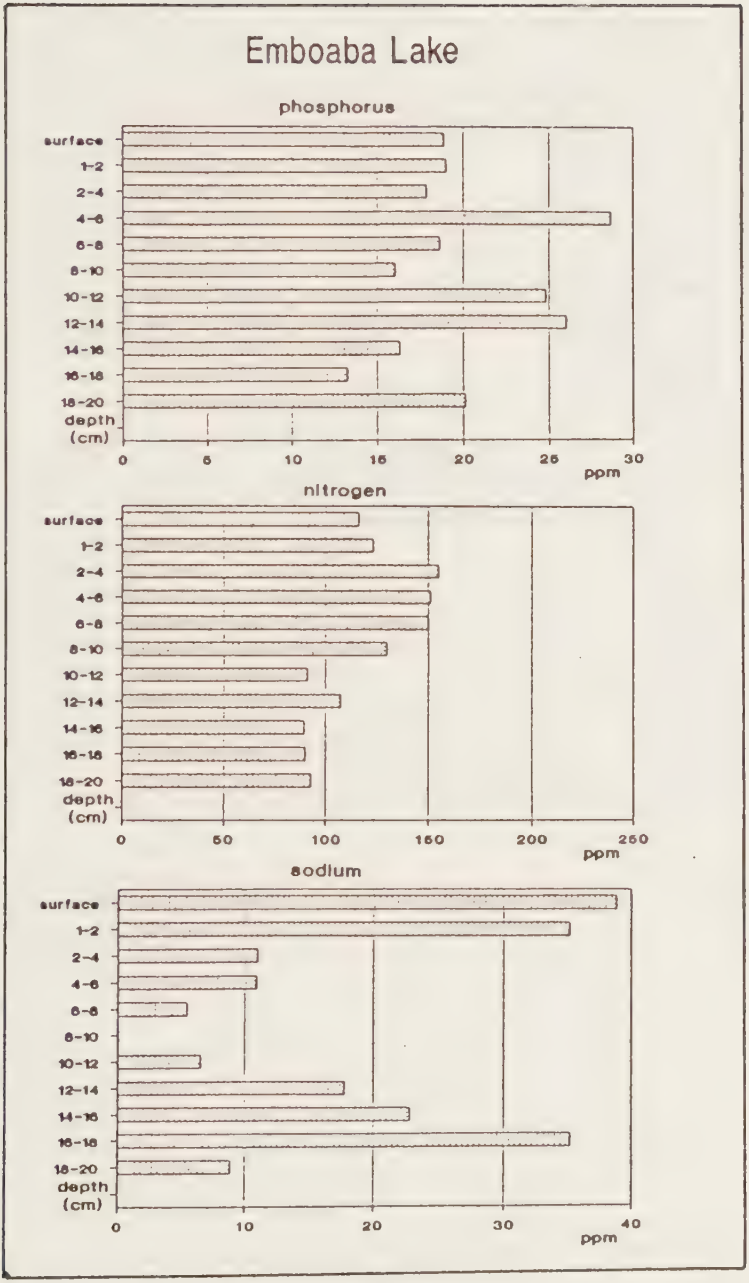


Fig.16


Emboaba Lake
phosphorus
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
5
10
15
20
25
30
ppm
nitrogen
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
50
100
150
200
250
ppm
sodium
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
10
20
30
40
ppm

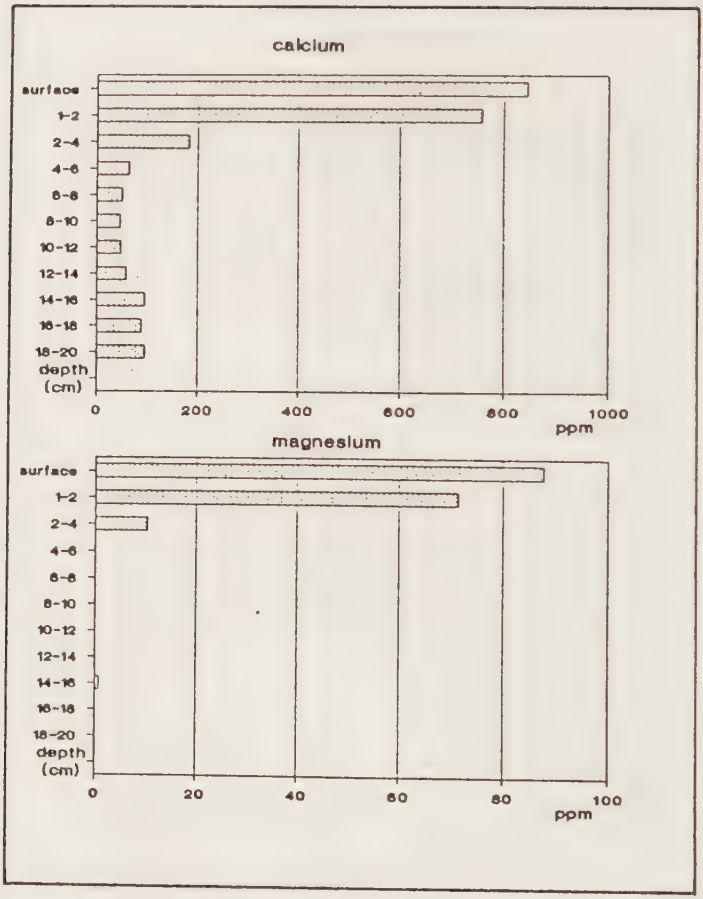

calcium
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
200
400
600
800
1000
ppm
magnesium
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
20
40
60
80
100
ppm

Fig.16

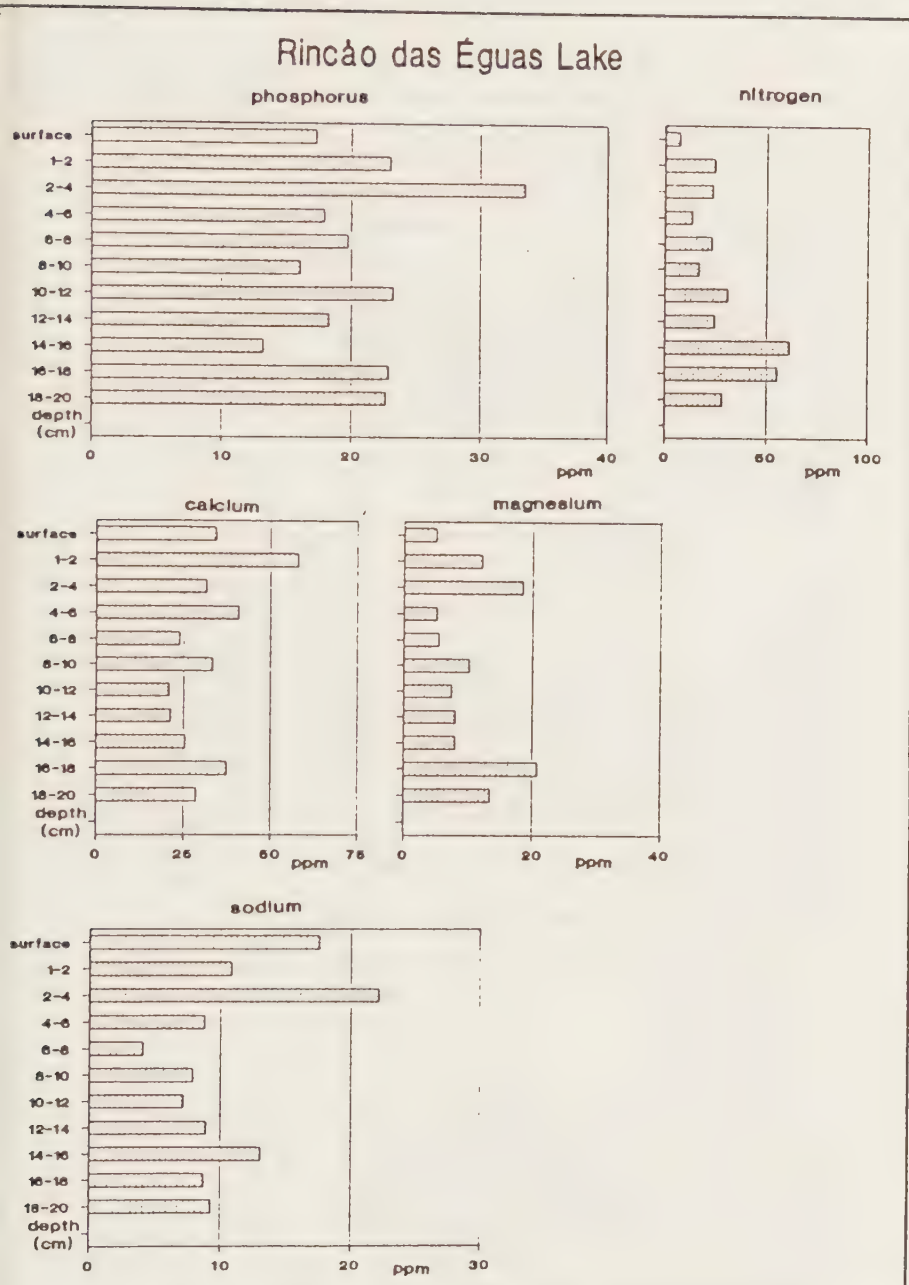
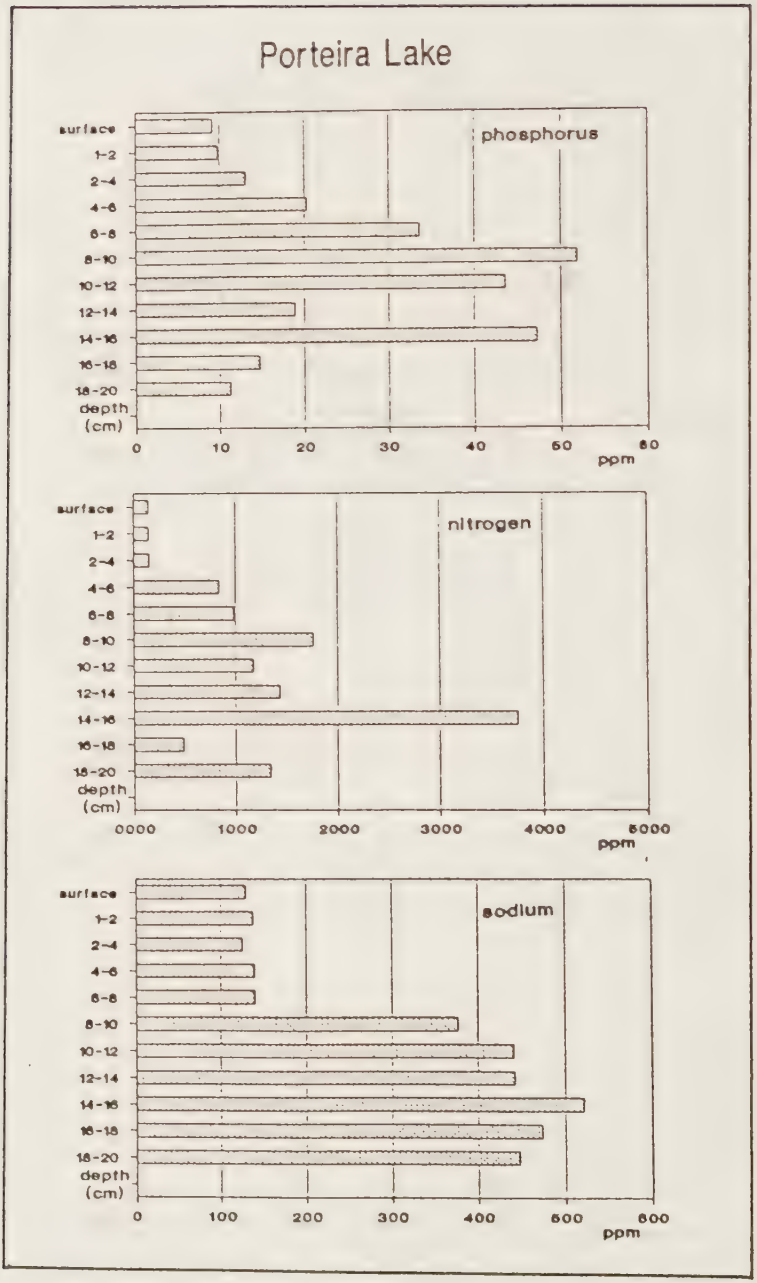

Rincão das Éguas Lake
phosphorus
nitrogen
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
10
20
30
40
ppm
0
50
100
ppm
calcium
magnesium
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
25
50
75
ppm
0
20
40
ppm
sodium
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
10
20
30
ppm

Fig.16


Porteira Lake
phosphorus
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
10
20
30
40
50
60
ppm
nitrogen
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0000
1000
2000
3000
4000
5000
ppm
sodium
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
100
200
300
400
500
600
ppm

Porteira Lake

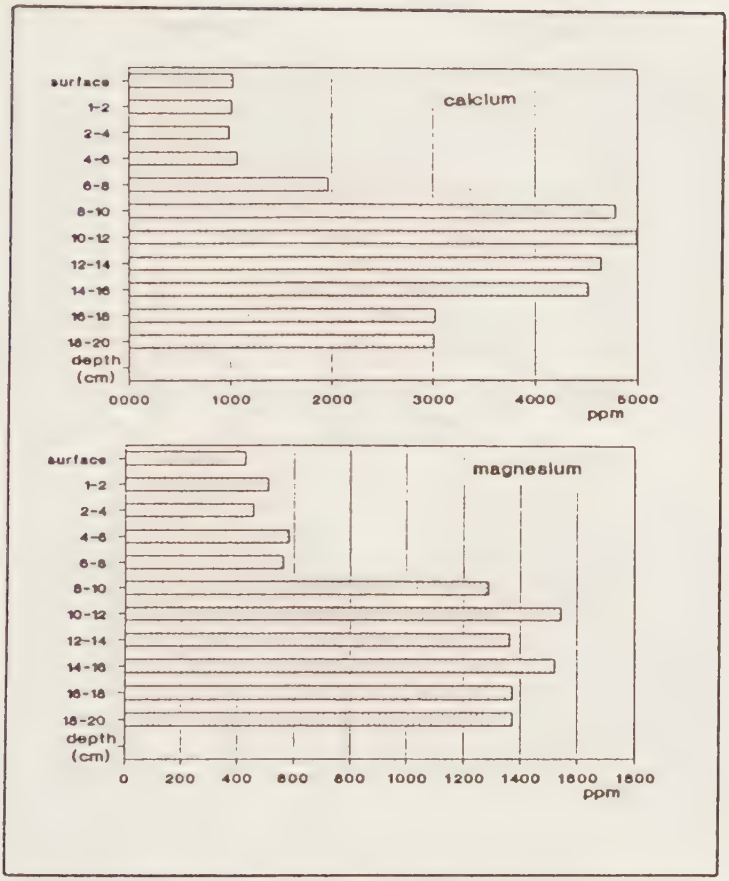


Fig.16

Barros-Solidão Lake

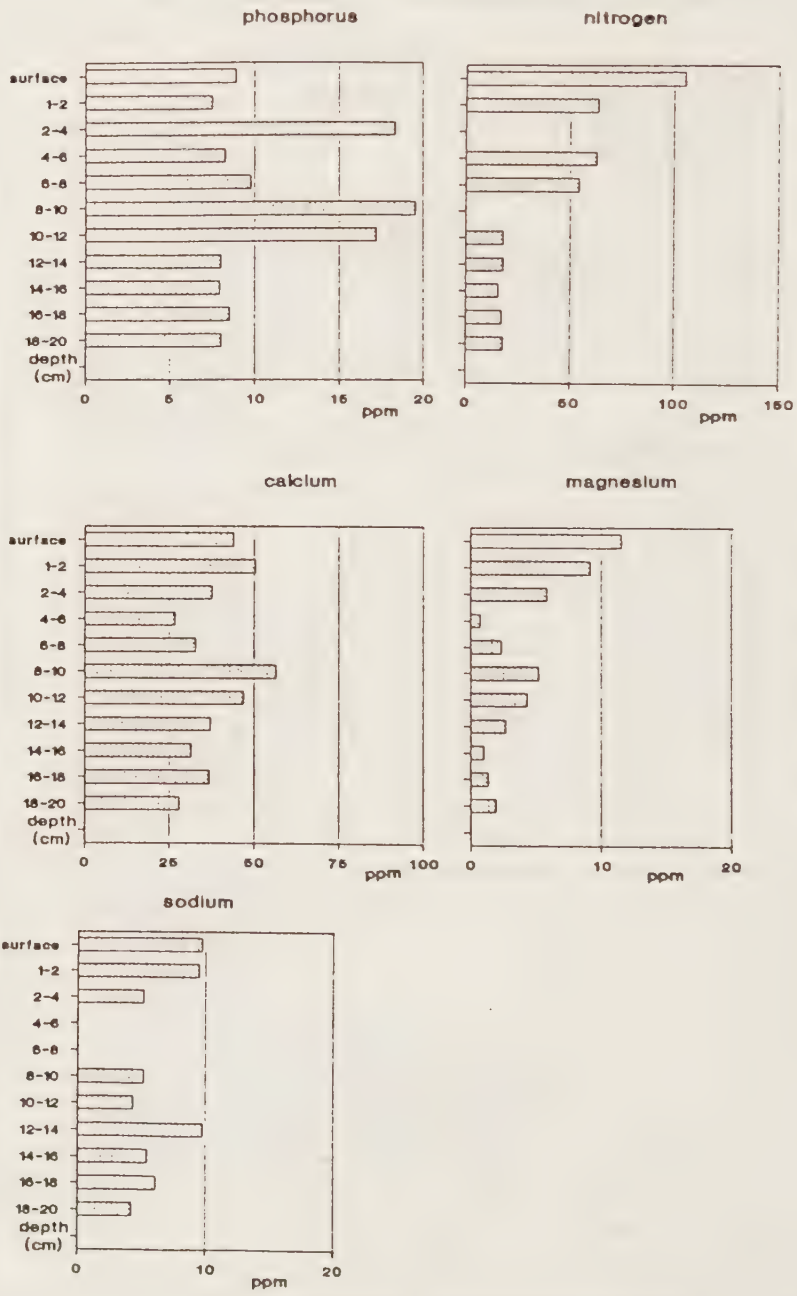


Fig.16

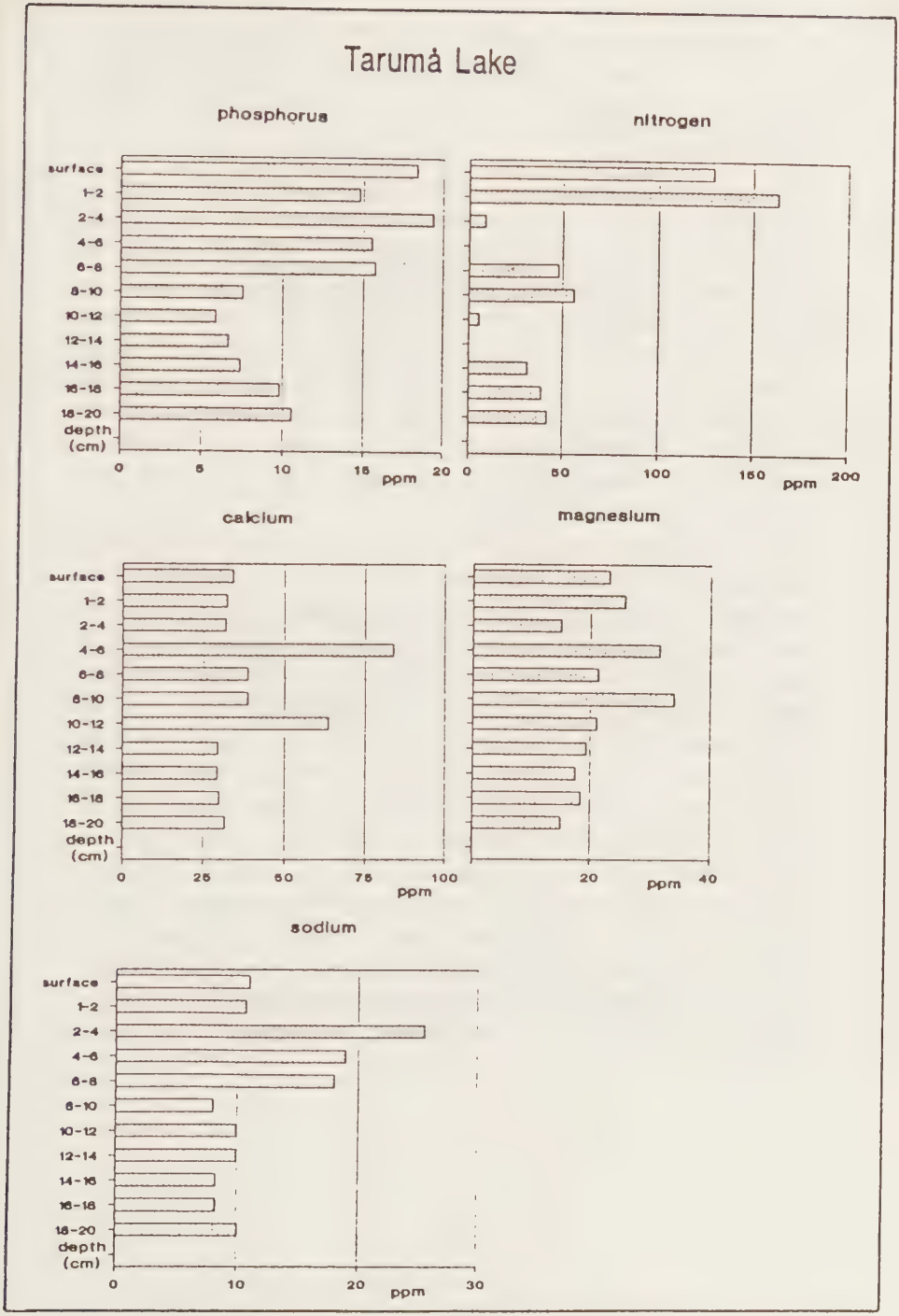

Tarumã Lake
phosphorus
nitrogen
surface
1-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
depth (cm)
0
5
10
15
20
ppm
0
50
100
150
200
ppm
calcium
magnesium
0
25
50
75
100
ppm
20
40
ppm
sodium
0
10
20
30
ppm

Fig.16

Patterns of Variation

Mineral element concentrations in superficial sediment layers are likely to be related to several factors that, to some extent, reflect the dynamics of the processes occurring in the water column, rather than the trophic status of some lakes. Sediment cores collected in the littoral zone are representative samples of such dynamics. In order to examine superficial sediment alterations among different lakes the relative mean deviation of each element was computed and compared between the whole sediment cores (Fig. 17) and the uppermost 2 centimeters (Fig. 18).

In a general pattern, the littoral zone of Porteira Lake appears to be composed of the more nutrient rich sediment, except for phosphorus. Such observation is in desagreement to earlier works since this lake presented the highest organic matter content (ARAUJO DE OLIVEIRA, 1990b). Regarding this nutrient, Caieira and Peixoto lakes have by far the highest concentrations. On the other hand, if only the upper 2 centimeters of sediment is compared, a pronounced change in the patterns is observed (Fig. 18) regarding nitrogen and calcium concentrations. Caieira Lake showed the highest nitrogen and calcium levels in the superficial sediments. Porteira Lake, followed by Emboaba Lake, presented superficial calcium enrichment in the upper sediment strata. Although with low proportions, sodium concentrations in the latter also showed a slight increase, if compared to other lakes.

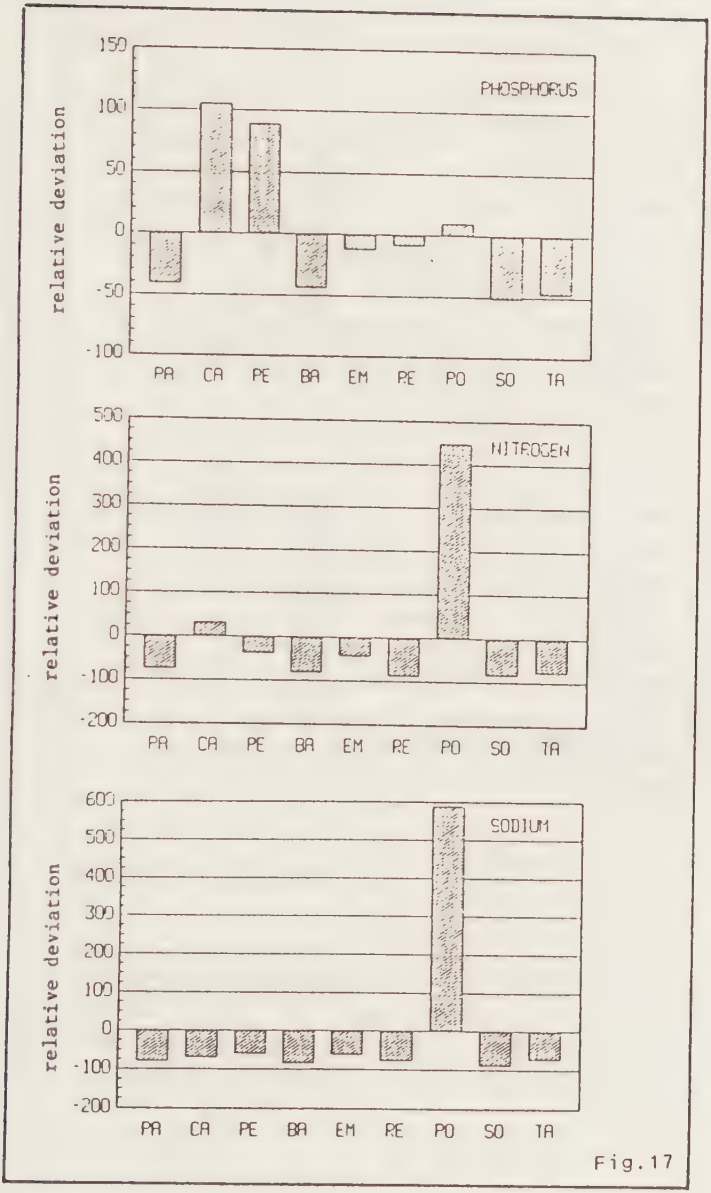

PHOSPHORUS
relative deviation
150
100
50
0
-50
-100
PA CA PE BA EM RE PO SO TA
NITROGEN
relative deviation
500
400
300
200
100
0
-100
-200
PA CA PE BA EM RE PO SO TA
SODIUM
relative deviation
600
500
400
300
200
100
0
-100
-200
PA CA PE BA EM RE PO SO TA

Fig.17

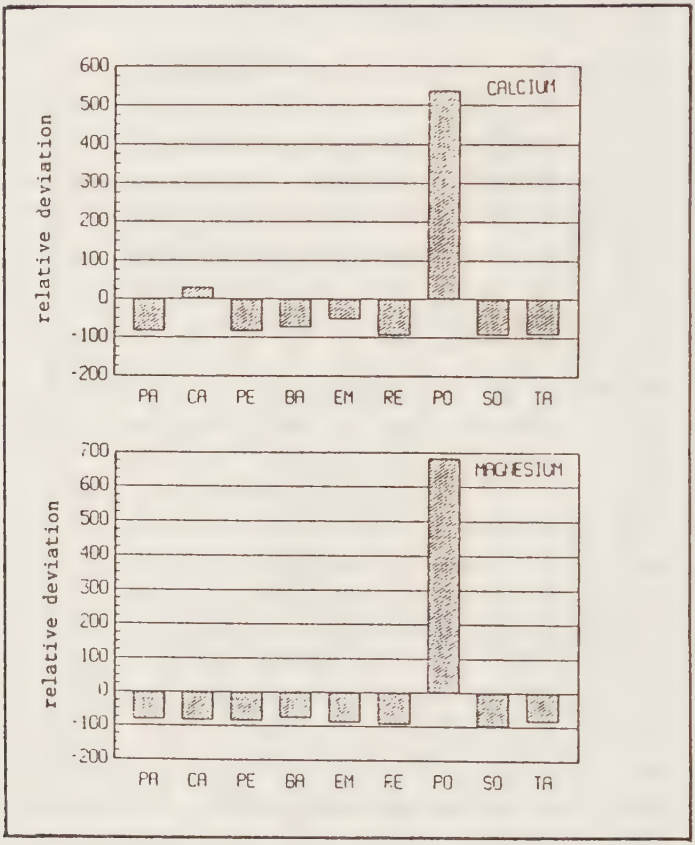


Figure 17: Mean element concentrations of sediment cores in the littoral zone of some coastal lakes. PA=Palmital; CA=Caieira; PE=Peixoto; BA=Barros; EM=Emboaba; RE=Rincão das Éguas; PO=Porteira; SO=Barros-Solidão; TA=Tarumã.

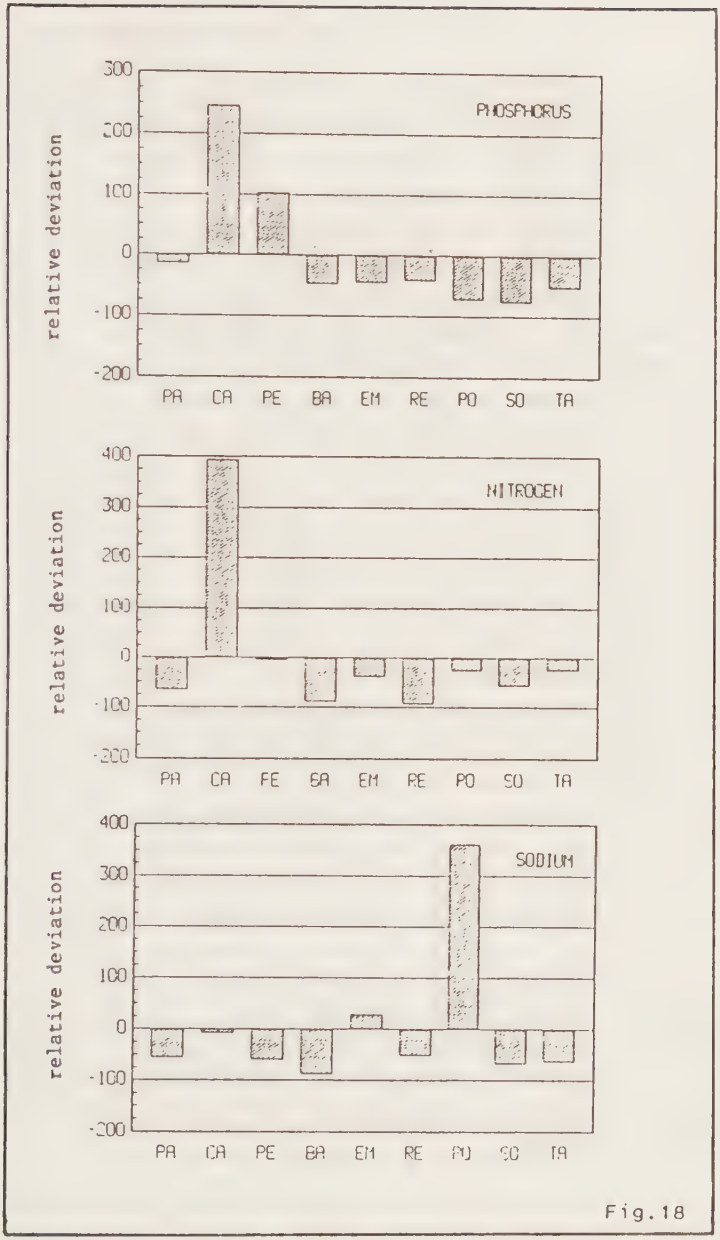

relative deviation
300
200
100
0
-100
-200
PHOSPHORUS
PA CA PE BA EM RE PO SO TA
relative deviation
400
300
200
100
0
-100
-200
NITROGEN
PA CA FE BA EM RE PO SO TA
relative deviation
400
300
200
100
0
-100
-200
SODIUM
PA CA PE BA EM RE PO SO TA

Fig.18

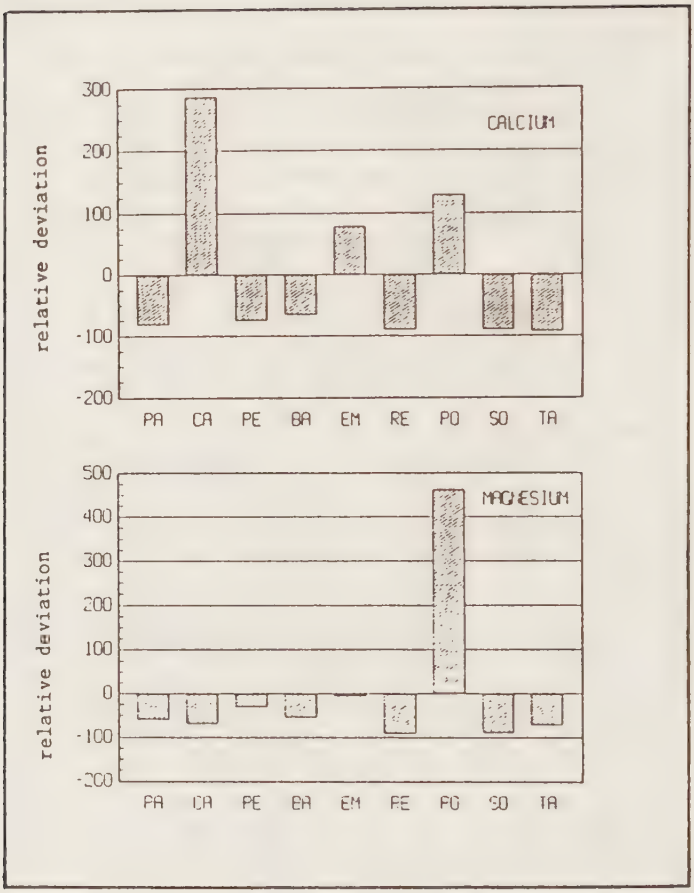


Figure 18: Mean element concentrations in the upper 2 centimeters of sediments in the littoral zone of coastal lakes. PA=Palmital; CA=Caieira; PE=Peixoto; BA=Barros; EM=Emboaba; RE=Rincão das Éguas; PO=Porteira; SO=Barros-Solidão; TA=Tarumã.

The same investigation was made in order to compare the heavy metal concentrations in the profile (Fig. 19) and in the uppermost 2 centimeters of sediment (Fig. 20). Lead was the only heavy metal whose mean levels did not differ greatly between the sediment profiles and the upper strata. This element presented higher concentrations in both Caieira and Emboaba lakes. All the other heavy metals showed different trends among the littoral zone, and delineated some peculiarities. Zinc accumulated especially in the upper sediment layers of Emboaba Lake, whereas in a gradient, Porteira Lake was more differentiated. Copper was also more expressively represented in this lake, but no special accumulations were observed in the superficial strata of sediments among all coastal lakes. The cadmium gradient differentiated Porteira, Peixoto, Caieira, and Emboaba lakes from the others. Nevertheless, Barros Lake presented and enrichment of this heavy metal in the upper strata. This fact is probably related to the high silty-clay suspended particles content of the lake (ARAUJO DE OLIVEIRA, 1983, 1990a).

The interrelationships of the chemical parameters along the sediment cores and in the uppermost strata showed that naturally occurring processes differentiated the littoral zones of lakes when treated separately. Principal components analysis based on the correlation among nutrient elements and heavy metals present in the sediment profile (up to 20 centimeters depth) indicated a tendency of nutrients to cluster strongly on the positive pole of the first axis (Fig. 21). This component accounted for 66.7% of the total variation suggesting common trends of increasing or decreasing along the sediment gradient. Phosphorus and cadmium grouped on the positive pole of the second component, that accounted for 23.8% of the total variance, whereas lead occurred alone

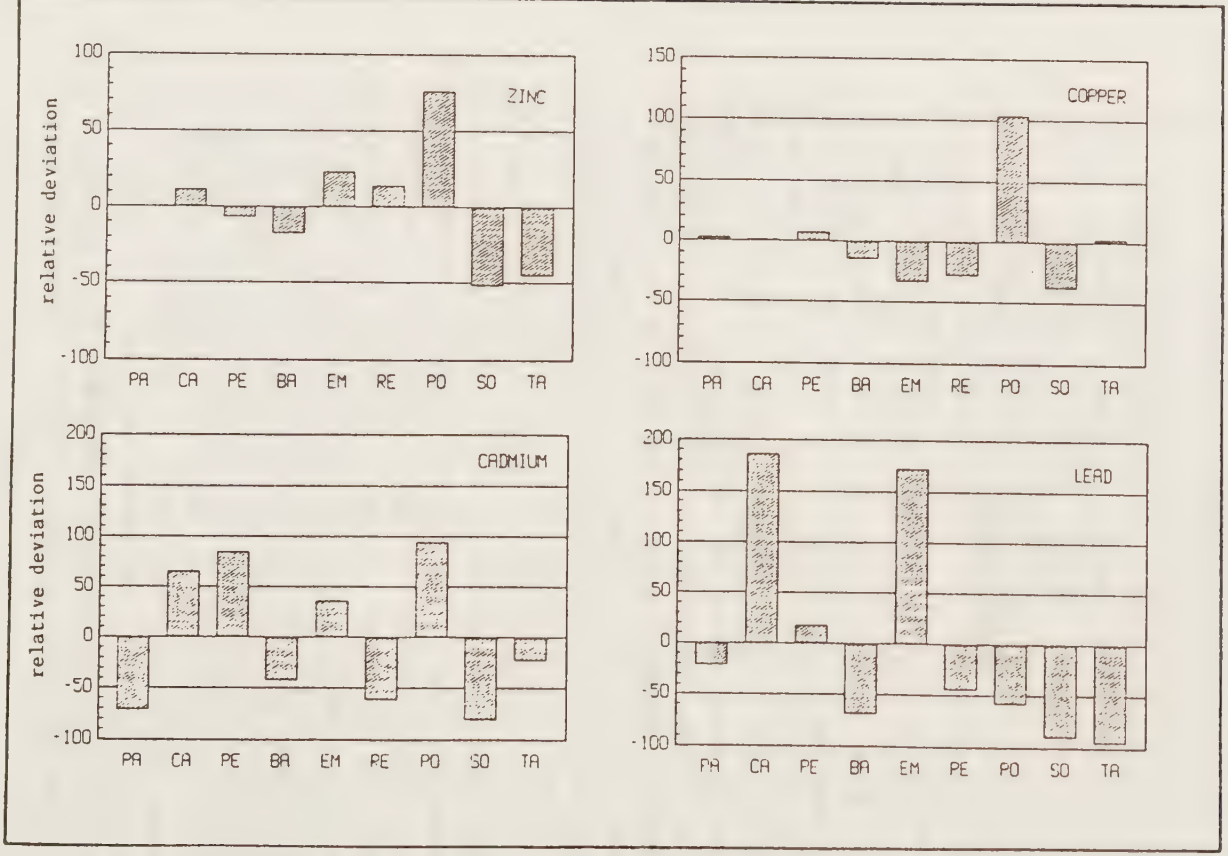


Figure 19: Mean heavy metal concentrations in a sediment profile in the littoral zone of coastal lakes. PA=Palmital; CA=Caieira; PE=Peixoto; BA=Barros; EM=Emboaba; RE=Rincão das Éguas; PO=Porteira; SO=Barros-Solidão; TA=Tarumã.

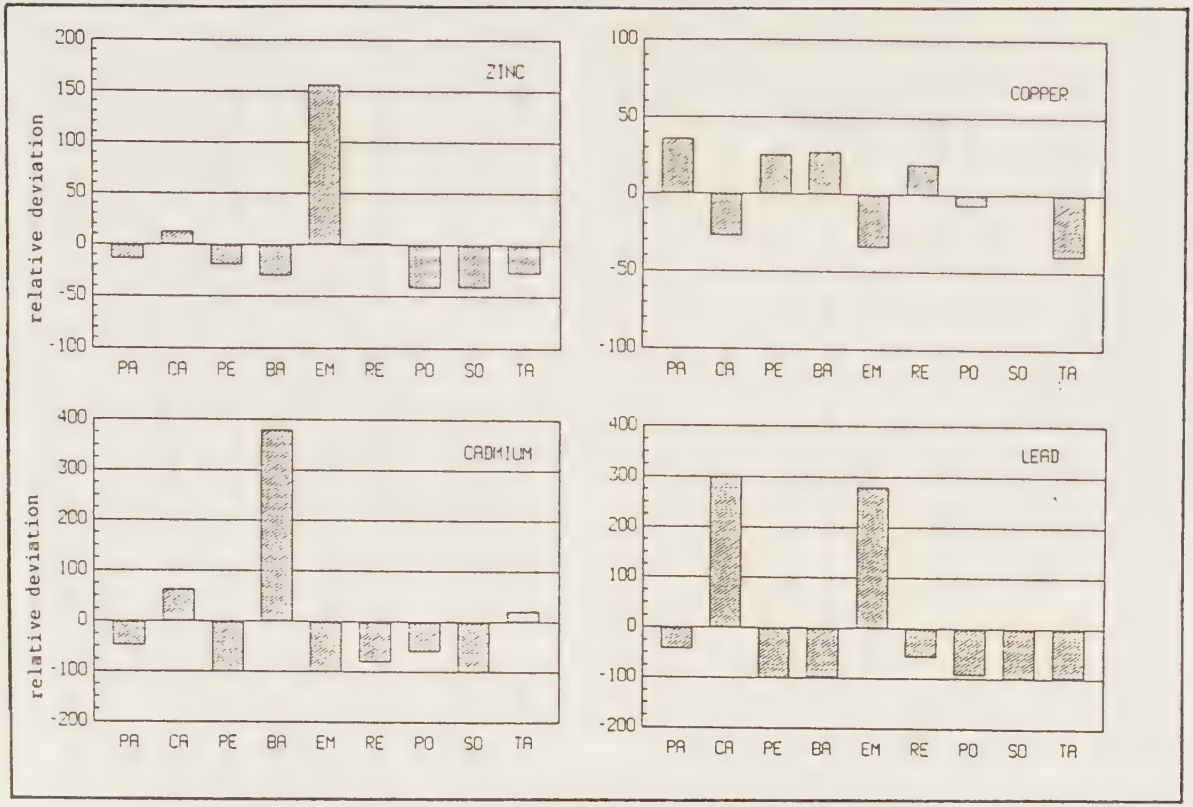


Figure 20: Mean heavy metal concentrations in the upper 2 centimeters of sediment in the littoral zone of coastal lakes. PA=Palmital; CA=Caieira; PE=Peixoto; BA=Barros; EM=Emboaba; RE=Rincão das Éguas; PO=Porteira; SO=Barros-Solidão; TA=Tarumã.

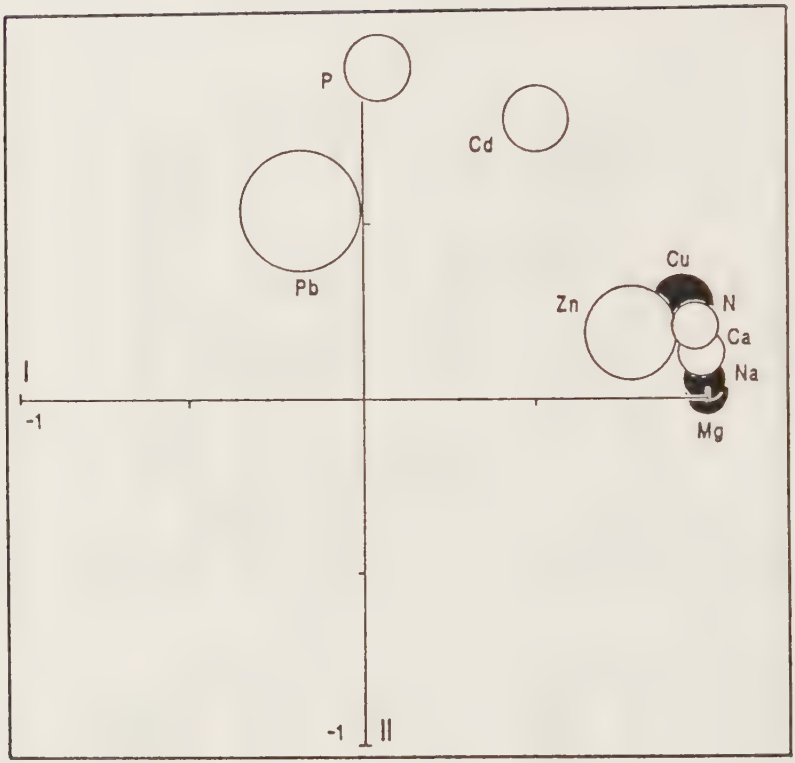


Figure 21: Principal components analysis of nutrients and heavy metal concentrations in a sediment profile of littoral zones of selected coastal lakes. Components I and II accounted for 66.7 and 23.8% of total variation. Component III (5.8% of total variation) is represented by circle diameter where open circles represent positive values and closed circles negative values.

on the third component. Such results show that approximately 29.6% of the variance in the sediment profile is not explained by patterns of increase or decrease in nutrients, but other mechanisms are responsible for the gradient in the littoral zone, not determined by the factors, but that can be reasonably related to anomalous strata in the sediment cores.

Nevertheless, when analysing the uppermost sediment strata by the principal components, the factor extracts four components (Fig. 22). On the positive pole of the first component, that accounted for 40.9% of the total variation, phosphorus, nitrogen and calcium grouped together; which suggests similar chemical relations. Another grouping is shown by sodium and magnesium on the second component, as well as by zinc, copper and lead on the third one. Cadmium grouped alone on the fourth component, that accounted for 9.5% of the total variance, which means that only this heavy metal showed great differences in accumulation patterns among the coastal lakes referred in this work.

As expected by the results showed above, the coastal lakes also presented different trends regarding the variables analysed, and according to the sediment gradient. The principal components analysis based on the correlation among the lakes, and taking into account the nutrients and heavy metals present in the sediment cores of the littoral zones, grouped Palmital, Rincão das Éguas, Barros-Solidão and Barros lakes on the positive pole of the first component (Fig. 23). This component alone accounted for 63.3% of the total variance. Caieira and Emboaba lakes grouped on the positive pole of the second axis, and Porteira Lake on the opposite pole of the same component, that accounted for 24.0% of the total variance. This shows that Caieira and Emboaba lakes present a similar pattern of heavy metal and nutrient

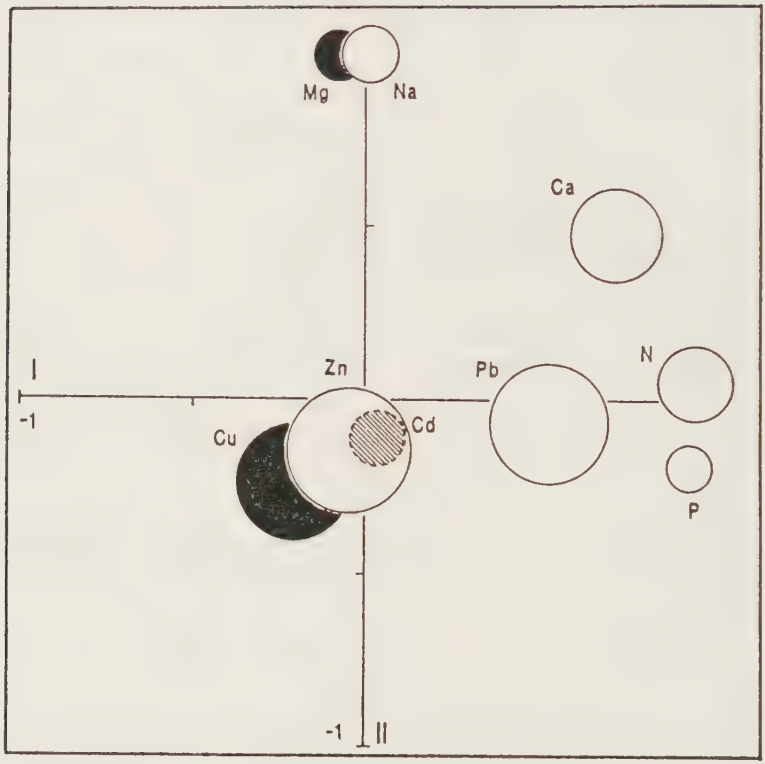


Figure 22: Principal components analysis of nutrients and heavy metal concentrations in the upper 2 centimeters of sediment in the littoral zone of selected coastal lakes. Components I and II accounted for 40.9 and 25.5% of total variation. Component III (16.7% of total variation) is represented by circle diameter where open circles represent positive values and closed circles negative values. Component IV (9.5% of total variation) is represented by dotted circles.

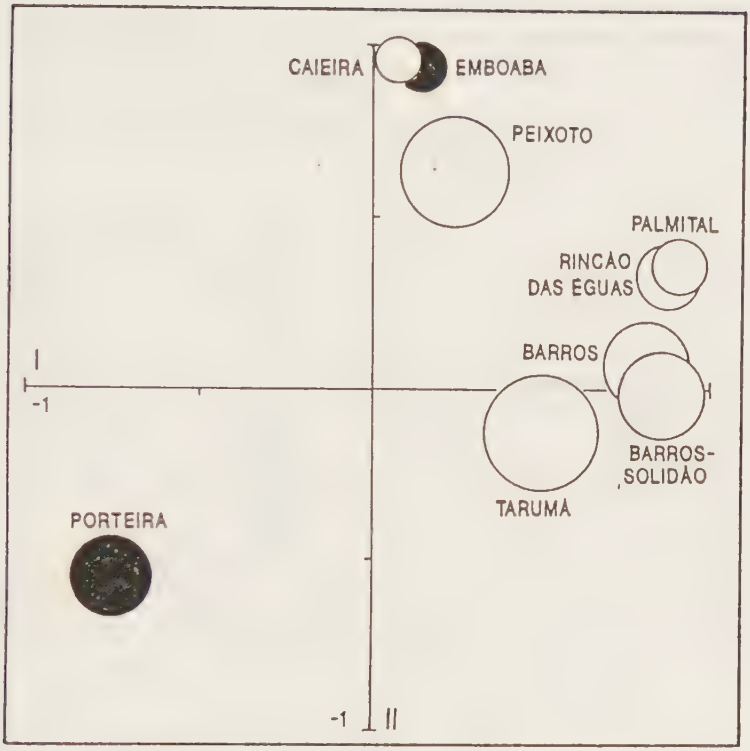


Figure 23: Components I (63.3% of total variation), II (24.0% of total variation), and III (7.3% of total variation) of the principal components analysis based on nutrients and heavy metal concentrations in a sediment profile in littoral zones of selected coastal lakes. Component III magnitude is represented by circle diameter where open circles represent positive values and closed circles negative values.

accumulations, opposite to Porteira Lake, but whose variations grouped them together, although distint from those that grouped lakes on the first axis. Tarumã and Peixoto lakes grouped on the third component, but the latter showed no defined pattern and is also associated with the second component.

Comparing the uppermost sediment strata by the principal components analysis, clear differences are still noted among the littoral zones (Fig. 24). Rincão das Éguas, Palmital and Barros-Solidão lakes, as observed in a sediment gradient, grouped together on the positive pole of the first component, that accounted for only 37.9% of the total variance. Nevertheless, Barros Lake grouped on the second component, together with Tarumã Lake. Porteira and Caieira lakes, showed opposite trends on the third axis, whereas Peixoto and Emboaba lakes showed opposite trends on the fourth component. The results obtained show a marked separation between littoral zones of Rincão das Éguas, Palmital and Barros-Solidão lakes and the others.

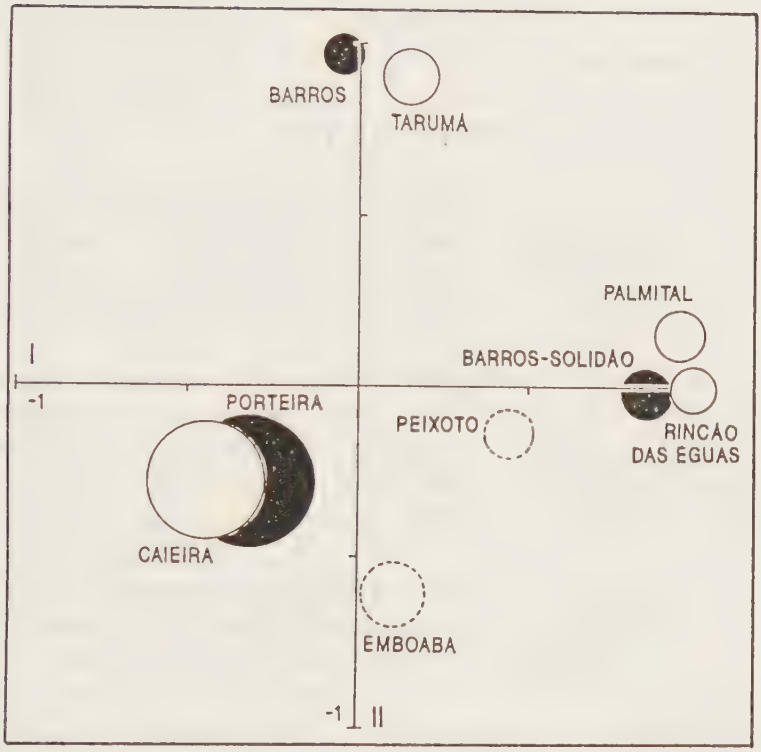


Figure 24: Components I (37.9% of total variation), II (25.0% of total variation), III (17.6% of total variation) and IV (13.2% of total variation) of the principal components analysis based on nutrients and heavy metal concentrations in the uppermost sediment strata of littoral zones in selected coastal lakes. Component III magnitude is represented by circle diameter where open circles represent positive values and closed circles negative values. Component IV is represented by dotted circles.

Heavy Metals

1. Emergent Macrophytes

Heavy metals in aquatic vegetation can differ widely. Differences of heavy metal accumulation in various organs of some emergent macrophytes collected in lakes of the Coastal Plain of Rio Grande do Sul were found for copper, zinc, cadmium and lead (Table 11).

Highest zinc and copper concentrations were found in leaves, inflorescences and roots of *Echinodorus grandiflorus*, a shoreline macrophyte. *Zizaniopsis bonariensis* showed the same tendency but with lower levels. However, cadmium contents in the stems were higher than in the leaves, but lower than in the inflorescences and roots. Although the concentrations of zinc and lead in freshwater plants have to be higher than those of less common metals (FÖRSTNER & WITTMANN, 1981), lead was detected only in roots from *E.grandiflorus* collected in Porteira Lake. Zinc concentrations in the stems of *E.grandiflorus* did not differ between samples collected in Saco de Tapes and Porteira Lake ($P>0.10$). However, the other heavy metals analysed showed a significant difference ($P<0.001$). All values presented above are extremely low when compared to the heavy metal accumulations of other water plants (WELSH & DENNY, 1980; FÖRSTNER & WITTMANN, 1981). Aluminium analysis performed in the stems and leaves of *Zizaniopsis bonariensis* harvested in Negra Lake showed that although the highest concentration occurred in the stems, older leaves accumulate more aluminium than the newer ones.

Metal concentrations in the cattail *Typha domingensis* showed similar levels either in the stems, or in the

Table 11: Heavy metal concentrations (µg/g dry weight) in different organs of emergent macrophytes from coastal lakes of Rio Grande do Sul. To each species n=15.

organ	Zn	Cu	Cd	Pb	
stems	5.69	2.18	0.66	0	*Z.bonariensis*
	42.78	7.40	0.57	0	*E.grandiflorus* [1]
	45.24	9.89	0.30	0	*E.grandiflorus* [2]
	32.06	8.86	0.22	0	*T.domingensis*
	66.18	4.97	0.65	0	*C.giganteus*
leaves	14.98	2.43	0.35	0	*Z.bonariensis*
	58.05	8.22	0.16	0	*E.grandiflorus* [1]
	42.47	10.39	0.27	0	*E.grandiflorus* [2]
	39.75	5.13	0.64	0	*C.giganteus*
inflor.	57.19	16.09	0.72	0	*E.grandiflorus* [1]
	27.34	7.85	0.40	0	*T.domingensis*
	12.84	4.57	0.63	0	*C.giganteus*
roots	55.97	7.26	2.01	0.13	*E.grandiflorus* [1]
	22.10	8.90	0.72	0	*E.grandiflorus* [2]
rhiz.	28.52	7.16	0.60	0	*T.domingensis*
	65.39	29.90	0.15	0	*C.giganteus*

inflor. = inflorescences; rhiz.=rhizomes
Zizaniopsis bonariensis = from Negra Lake
Echinodorus grandiflorus [1] = from Porteira Lake
Echinodorus grandiflorus [2] = from Saco de Tapes
Typha domingensis = from Tramandai swamp
Cyperus giganteus = from southern Saco de Tapes

inflorescences and rhizomes, but cadmium was slightly lower in the stems. Nevertheless, total zinc concentrations are higher than values found by AUCLAIR (1979) for *T.angustifolia* in wetlands.

Cyperus giganteus showed the highest zinc concentrations in stems and rhizomes, but low values were observed in the inflorescences. The rhizome stored zinc and copper more than the other macrophytes.

2. Scirpus californicus

2.1. Coastal Lakes

Heavy metal accumulations in different organs of the bulrush *S.californicus* collected in some lakes of the Coastal Plain of Rio Grande do Sul (Table 12) showed that in Peixoto Lake the zinc, copper and cadmium contents were three times higher in leaves and inflorescences than in stems. This was the only lake where some accumulation of lead was observed in the inflorescences. No other lead accumulation was detected in any other lake. Emboaba Lake showed the highest accumulation of zinc in the rhizomes while copper and cadmium were higher in leaves. This lake is located near a traffic road and atmospheric inputs could explain the high heavy metal values. Heavy metal values detected in bulrushes from Peixoto Lake, otherwise, could be explained by the proximity to a town.

The bulrushes from Porteira Lake showed a high accumulation of zinc in the inflorescences, contrasting with the rhizome values which were almost six times lower. Although copper and cadmium were slightly higher in the inflorescences, no differences were detected between stems and leaves. The rhizomes showed the lowest heavy metal accumulations.

Table 12: Accumulations of zinc, copper, cadmium and lead (µg/g dry weight) in different organs of the bulrush *S.californicus* in some coastal lakes during summer.

	Zn	Cu	Cd	Pb	lake (n=15)
stems	20.91	2.47	0.20	0	Peixoto
	16.94	4.53	1.37	0	Porteira
	16.32	1.65	0.66	0	Caieira
	10.43	2.22	0.63	0	Emboaba
	14.19	2.74	0.68	0	Palmital
	17.61	1.74	0.58	0	R.das Éguas
	15.87	2.06	0.52	0	Barros
	13.81	3.28	0.91	0	Tarumã
	14.83	0.87	0.61	0	B.Solidão
leaves	67.72	7.04	2.66	0	Peixoto
	18.67	3.08	1.21	0	Porteira
	20.70	1.87	1.67	0	Caieira
	51.19	7.34	2.61	0	Emboaba
	34.20	4.81	1.45	0	Palmital
	50.62	26.99	3.49	0	R.das Éguas
	34.31	5.45	2.31	0	Barros
	35.50	35.73	2.66	0	Tarumã
	10.83	3.80	0.60	0	B.Solidão
inflor.	52.31	10.89	1.56	0.41	Peixoto
	42.88	6.98	1.75	0	Porteira
	56.86	4.74	1.36	0	Caieira
	36.96	5.83	1.11	0	Barros
rhiz.	7.76	1.50	0.46	0	Porteira
	127.41	3.77	0.23	0	Emboaba

inflor.=inflorescences; rhiz.=rhizomes

S.californicus from Caieira Lake presented zinc and copper accumulated in the inflorescences, although cadmium values were higher in leaves. In the Palmital, Rincão das Éguas and Tarumã lakes, the highest heavy metal contents were detected in leaves. The latter ones showed significant copper accumulations.

S.californicus from Barros Lake showed higher metal contents in leaves and inflorescences. Although the lake is located near a heavy-traffic road, heavy metal concentrations were relatively low compared to other lakes in the same region. Results could be related to its location and to the predominant wind-direction blowing in the Coastal Plain almost year round (ARAUJO DE OLIVEIRA, 1990a). For this reason, atmospheric inputs precipitate outside the littoral zone but not where the bulrushes were harvested.

Barros-Solidão Lake showed an accumulation of copper in leaves, whereas other metals were homogeneously distributed either in stems or in leaves. From all studied lakes, that was the only lake where the heavy metal concentrations in the bulrushes were low, except for copper in the leaves.

There are considerable differences in the heavy metal concentrations of different organs of *S.californicus*. When the element concentrations between sets of the littoral zone of different lakes are analysed statistically, the variations between organs are greater than those between individuals. Total zinc and copper levels of *S.californicus* from Peixoto Lake lie within the range quoted by AUCLAIR (1979) to *S.fluviatilis* and *S.validus*, but in all other lakes, concentrations are lower. Bulrushes from Rincão das Éguas and Tarumã lakes, exceptionally, presented higher copper contents than those mentioned above.

Analysis of between-site variance of the total macrophyte showed that the lakes differed significantly

only in respect of zinc concentrations ($F=2.418$; $d.f.=8,57$; $P<0.05$).

2.2. Saco de Tapes

Studies carried out in bulrushes harvested from different edges of Saco de Tapes demonstrated that heavy metal concentrations in such a type of emergent macrophyte can differ widely in the same aquatic system (Table 13).

In the southern margin of Saco de Tapes, lead decreased in the leaves, and the decrease in zinc was not significant in the stems ($P>0.20$), in the leaves ($0.10>P>0.05$) and in the inflorescences ($P>0.50$) during winter months. Copper increased significantly in the leaves ($t=6.046$; $d.f.=22$; $P<0.001$) and inflorescences ($t=-2.639$; $d.f.=22$; $P<0.05$) and cadmium content was significantly higher in the inflorescences ($t=-4.869$; $d.f.=22$; $P<0.001$) in the same period. The rhizomes showed the highest zinc and copper accumulations during summer. New inflorescences appear to accumulate more zinc and copper than older ones.

In the eastern margin, considering the two seasons, there was a slight increase of heavy metal contents in the stems during winter, but a significant difference was detected in the copper concentrations ($t=-3.379$; $d.f.=32$; $P<0.01$). Nevertheless, cadmium decreased in leaves ($t=3.577$; $d.f.=22$; $P<0.01$) and inflorescences ($t=4.706$; $d.f.=28$; $P<0.001$), whereas an expressive accumulation of zinc and copper occurred both in the leaves ($t=-3.711$; $d.f.=22$; $P<0.01$ and $t=-4.624$; $d.f.=22$; $P<0.001$, respectively) and in the inflorescences ($t=-3.467$; $d.f.=29$; $P<0.01$ and $t=-9.967$; $d.f.=28$; $P<0.001$, respectively). The increasing lead concentration was not

Table 13: Heavy metals concentrations (µg/g dry weight) in different organs of *S.californicus* from Saco de Tapes during summer (su) and winter (w) seasons. To each margin n=54.

	Zn	Cu	Cd	Pb	margin
stems	9.17	0.89	0.54	0	southern - su
	13.81	0.81	0.58	0	southern - w
	10.69	0.91	0.31	0	eastern - su
	11.19	2.20	0.40	0.33	eastern - w
	12.52	0.56	0.50	0	western - su
	10.48	0.54	0.64	0	western - w
leaves	31.61	1.07	0.90	0.16	southern - su
	15.58	3.47	1.05	0	southern - w
	16.01	1.45	0.76	0.13	eastern - su
	28.75	5.28	0.26	3.08	eastern - w
	24.51	2.37	1.34	0	western - su
	26.75	0.57	0.50	0	western - w
inflor.	38.73	2.75	1.18	0	southern - su
	36.46	4.03	2.23	0	southern - w
	16.66	1.15	0.90	0.82	eastern - su
	28.58	5.88	0.39	1.23	eastern - w
	28.68	2.41	1.38	0.29	western - su
	31.64	4.97	0.73	0	western - w
rhiz.	57.01	4.07	0.41	0	southern - su

inflor.=inflorescences: rhiz.=rhizomes

significant in the inflorescences ($P>0.15$) but in the leaves ($t=-6.915$; $d.f.=22$; $P<0.001$).

In the western margin, where anthropogenic effects are high, the leaves and the inflorescences of *S. californicus* showed the highest heavy metal concentrations, pattern also observed in the other bulrushes from different margins. Zinc concentrations in stems, leaves and inflorescences were not significantly different during the two seasons ($P>0.30$). Although copper concentrations did not differ in the stems between summer and winter ($P>0.80$), the decreasing concentration in the leaves ($t=4.601$; $d.f.=16$; $P<0.001$) and the increasing concentration in the inflorescences ($t=-5.241$; $d.f.=22$; $P<0.001$) were significant. Cadmium in the stems showed significantly higher values in winter ($t=-3.151$; $d.f.=22$; $P<0.01$), whereas in the leaves this heavy metal decreased ($t=3.681$; $d.f.=16$; $P<0.01$) and in the inflorescences the difference was marginal ($t=2.032$; $d.f.=22$; $0.06>P>0.05$).

Regarding heavy metal concentrations, the bulrushes collected in the eastern margin seem to accumulate more lead than the other ones. Fine-grained fractions of sediments influenced by physical processes and organic substances are transported and depositioned in this margin (GUERRA, 1988). As heavy metals can be carried by suspended sediments, and fine sediments accumulate in shallow or intertidal areas, probably the sediments settled on the eastern margin of Saco de Tapes promote the enrichment of the substratum with heavy metals.

Heavy metal evaluation in different organs of *S. californicus* was also done during the spring and autumn months. Table 14 presents results obtained in bulrushes harvested in the western margin of Saco de Tapes, near the town of Tapes, and in the northeastern edge, near a stream which drains water from a swampy area to the system.

Table 14: Heavy metal concentrations (µg/g dry weight) in *S.californicus* from two different margins of Saco de Tapes during autumn (a) and spring (s). To each margin n=54.

	Zn	Cu	Cd	Pb	margin
stems	15.37	2.13	0.62	0.21	western - s
	14.28	0.59	0.59	0	western - a
	11.74	0.69	0.46	0	northeast - s
	14.39	0.47	0.50	0	northeast - a
leaves	42.01	2.11	1.24	0.16	western - s
	32.72	2.58	2.50	0	western - a
	25.64	1.59	2.33	0	norhteast - s
	56.79	1.79	1.45	0	northeast - a
inflor.	35.43	2.07	0.64	0.05	western - s
	24.65	2.98	1.17	0	northeast - s
	25.26	0.41	2.23	0	norhteast - a
rhiz.	66.92	0.51	1.37	0	western - s
	41.12	5.12	0.90	0	western - a
	37.12	2.28	1.74	0	northeast - s

inflor.=inflorescences; rhiz.=rhizomes

Although the rhizomes of the bulrushes harvested in the western margin showed a decreasing concentration of zinc ($t=3.070$; $d.f.=10$; $P<0.05$) and cadmium ($t=3.302$; $d.f.=10$; $P<0.01$), copper increased from spring to autumn ($t=-40.546$; $d.f.=10$; $P<0.001$), and lead was absent in both seasons. Lead concentrations decreased in the stems and leaves whereas in the new inflorescences it appeared with very low values after the winter. Copper was

significantly different in the stems ($t=4.555$; $d.f.=34$; $P<0.001$), but not zinc and cadmium ($P>0.40$ and $P>0.75$, respectively). Cadmium and copper concentrations in the leaves were higher in autumn than in spring ($t=-7.479$; $d.f.=34$; $P<0.001$ and $t=-2.215$; $d.f.=34$; $P<0.05$, respectively). Although in the western margin a slight decrease in the zinc contents was detected in the leaves, from spring to autumn, the difference was not significant ($0.10>P>0.05$).

During the autumn and spring, the leaves and the inflorescences also showed higher heavy metal concentrations than those of the stems also during autumn and spring. Exception is made for copper in the bulrushes collected in the western margin during the spring and in the northeast during autumn. Nevertheless, the rhizome as a reserve organ appears to accumulate more zinc and copper than cadmium or even lead.

Regarding zinc concentrations in the leaves of *S. californicus* of the northeastern margin, a significant increase was observed from spring to autumn ($t=-4.707$; $d.f.=34$; $P<0.001$), but copper and cadmium accumulations did not differ between these two seasons ($P>0.95$ and $P>0.05$, respectively).

The stems showed a decrease of copper concentrations ($t=4.165$; $d.f.=34$; $P<0.001$), but the same was not observed with zinc and cadmium ($P>0.15$ and $P>0.30$, respectively). Although zinc contents in the inflorescences did not differ between the two seasons ($P>0.60$), a decrease of copper ($t=6.207$; $d.f.=13$; $P<0.001$), and an increase of cadmium concentrations ($t=-6.493$; $d.f.=13$; $P<0.001$) occurred.

A comparison between seasons and concentrations of heavy metals in different organs of *S.californicus* was performed by the analysis of variance (One-way ANOVA).

Zinc concentrations in the inflorescences and leaves of macrophytes harvested during winter in the eastern

margin were significantly different from stems, and from bulrushes collected during summer ($F=12.578$; $d.f.=5,83$; $P<0.001$), but leaves differed between the two seasons. The same tendency was observed on copper, excepting that leaves during summer and winter showed different concentrations of this metal, and a significant difference was obtained between stems from both seasons ($F=21.470$; $d.f.=5,82$; $P<0.001$). Cadmium concentrations in the inflorescences differed from those in the stems during summer and from the inflorescences and stems during winter ($F=6.480$; $d.f.=5,82$; $P<0.001$). No significant variations were obtained in the cadmium concentrations between bulrushes harvested in the winter and summer, except for the inflorescences in summer. Lead concentrations in leaves and stems during winter were statistically different ($F=11.486$; $d.f.=4,65$; $P<0.001$). A significant variation was also obtained between lead concentrations in leaves in winter and leaves and inflorescences in summer. Nevertheless, concentrations in the inflorescences did not vary between the two seasons.

In the southern margin of Saco de Tapes zinc concentrations in the leaves of *S.californicus* collected during summer differed from those in the stems, but not from other organs of the bulrush, even when compared to the winter period. In both seasons inflorescences and rhizomes differed from stems and leaves collected in the winter, and from stems in summer ($F=18.373$; $d.f.=6,69$; $P<0.001$). Copper concentrations in inflorescences and rhizomes during summer, as well as in leaves and inflorescences during winter, differed from stems in both seasons ($F=23.70$; $d.f.=6,69$; $P<0.001$). Cadmium concentrations varied between inflorescences and stems during summer, and during winter the inflorescences differed from all other organs ($F=22.309$; $d.f.=6,69$; $P<0.001$). Cadmium concentrations in the rhizomes did not

differ from other values obtained in the same set during both seasons, except for inflorescences in winter.

During all seasons the zinc concentrations of the leaves differed from those of stems in the western margin of Saco de Tapes ($F=24.308$; $d.f.=12,149$; $P<0.001$). Copper concentrations of bulrushes analysed during spring showed a significant variation when comparing stems collected in summer and autumn ($F=23.652$; $d.f.=12,149$; $P<0.001$). Concentrations of copper in leaves also varied between autumn and winter months. Leaves and inflorescences differed from stems and rhizomes in summer. Except for rhizomes in spring, cadmium concentrations in the leaves of bulrushes harvested in autumn differed from all other values obtained in all seasons ($F=27.719$; $d.f.=12,149$; $P<0.001$). Rhizomes in spring differed from stems in autumn and summer. Leaves in spring and summer differed from stems, except in winter. In sets were lead was present, no differences were obtained between the concentrations in the bulrushes during all the year ($P>0.60$).

In the northeastern margin, zinc concentrations in the inflorescences, leaves, and rhizomes were highly different from stems during spring ($F=24.830$; $d.f.=6,86$; $P<0.001$), but not during autumn. In both seasons copper concentrations differed between leaves and stems ($F=23.248$; $d.f.=6,86$; $P<0.001$). During autumn, a significant difference was observed between the inflorescences and leaves. The rhizomes differed from stems in both seasons. However, the inflorescence during spring was the most different organ. Cadmium concentrations in the rhizomes during spring, in the inflorescences during autumn, and in the leaves during autumn and spring, were significantly different from stems in both seasons ($F=17.407$; $d.f.=6,86$; $P<0.001$).

Nutrients

Mineral nutrients taken up from or lost to the aquatic system, may also be transported to or from the rhizomes (BJÖRK, 1967; KVET, 1975, GRANÉLI, 1983). Studies carried out in *Phragmites* stands revealed that some of the essential elements absorbed from the environment are returned to the rhizomes at the end of the vegetation period (BJÖRK, 1967), or to the water and sediment (GRANÉLI, 1983). Some elements are preserved within the plant, whereas others are not transported to the rhizomes in autumn. Transport of elements occurs from the bottom via the plant to the water and superficial sediment layer in a lake. Moreover, essential nutrients can be preserved and repeatedly utilized in the development of the macrophyte. Therefore, it can be difficult to establish a direct correlation between actual environmental conditions and the development of the plant. Nevertheless, the concentration of an element can indicate the availability of that element in the environment in which the macrophyte grows (GERLOFF & KROMBHOLZ, 1966).

SEDDON (1972) stressed that at any given solute concentration, high hardness ratio is correlated with greater number of aquatic macrophytes and with the presence of more exacting species.

CARIGNAN & KALFF (1979) mentioned that in studies dealing with relatively long-lived organisms such as macrophytes drawing nutrients from complex systems like soils or sediments, short-term tracer dilution technique or even chemical means are not representative. Therefore, a constant monitoring including water-sediment-macrophyte interrelationships is important for the understanding of mechanisms and chemical processes which take part in such a system.

Mineral concentrations in emergent macrophytes have been largely reported (DYKYJOVA, 1973b, c; KVET, 1973, 1975; GAUDET, 1975; AUCLAIR, 1979; VAN DER LINDEN, 1980; DYKYJOVA & KVET, 1983; GRANÉLI, 1983, 1985, GRANÉLI et al., 1983; HUEBERT & GORHAM, 1983). Some of these authors have pointed out that between-site variation in mineral contents of emergent macrophytes is usually larger than within-site variation.

1. Emergent Macrophytes

Elemental composition of some emergent macrophytes collected in the coastal lakes of Rio Grande do Sul are showed in Table 15.

Echinodorus grandiflorus, a shoreline species, showed a slight decrease of mineral concentrations in the roots, but the potassium content was higher in the stems in both sampled sites.

Compared to the other macrophytes, *Zizaniopsis bonariensis* showed a very low nitrogen content in the stems. Although calcium and magnesium concentrations were also low in the stems, sodium and potassium were higher. Nevertheless, it was observed that calcium accumulates in old leaves but potassium is lost.

Except for sodium in the inflorescences and calcium concentrations, all other elements showed lower values in the rhizomes than in other organs of the cattail *Typha domingensis*. KVET (1975) in his study with *T.latifolia* has shown that calcium is stored rather in the stems than in inflorescences, and magnesium is contained in the stems and inflorescences during the growing season. Results presented in Table 15 for *T.domingensis* show that most of the calcium is stored also in the inflorescences, and magnesium shows the similar results as those observed by KVET for the cattail in temperate regions. In

Table 15: Mean mineral concentrations (µg/g dry weight) of emergent macrophytes from some coastal lakes of Rio Grande do Sul during summer. For each species n=15.

	P	N	Ca	Mg	Na	K	species
stems	6377	13534	5977	2057	3740	87150	*E.g.*[1]
	2589	8432	6940	1743	10107	84693	*E.g.*[2]
	1287	3670	6330	3173	5920	45770	*T.d.*
	1177	291	994	579	7860	22447	*Z.b.*
	-	-	760	610	3390	5410	*C.g.*
leaves	4983	13117	6780	2953	5157	39430	*E.g.*[1]
	2923	8627	9550	5780	9250	27927	*E.g.*[2]
	1552	5554	1967	681	2625	4770	*Z.b.*
	429	2277	3830	1350	4560	13470	*C.g.*
inflor.	-	-	6493	6597	4007	42500	*E.g.*[2]
	3093	8137	7567	2970	450	16983	*T.d.*
	-	-	2680	1610	2860	20720	*C.g.*
roots	3136	9405	4563	3050	1027	63163	*E.g.*[1]
	1871	7801	2890	1810	4317	14613	*E.g.*[2]
rhiz.	561	1687	6780	1217	4163	6497	*T.d.*
	-	-	2770	1230	0	5490	*C.g.*

inflor.=inflorescences; rhiz.=rhizomes

E.g.[1] =*Echinodorus grandiflorus* from Saco de Tapes

E.g.[2] =*E.grandiflorus* from Porteira Lake

T.l.=*Typha domingensis*

Z.b.=*Zizaniopsis bonariensis*

C.g.=*Cyperus giganteus*

accordance with results obtained to other species of cattail (KVET, 1975; BOYD, 1970b), the potassium concentration in *T.domingensis* also surpassed that of nitrogen. In *T.latifolia* a high concentration of sodium is associated with non-assimilatory tissues (KVET, 1975) and a decreasing potassium concentration is related to the gradually prevailing senescence of the stems. BOYD & HESS (1970) have already reported some of the variations in nutrient concentrations of *Typha* as genetic variability due to hybridization.

Cyperus giganteus appears to have the lowest nutrient concentrations in stems with a slight increase in the leaves and inflorescences. Although no sodium was found in the rhizomes, calcium and magnesium concentrations are similar to those found in the leaves and inflorescences. Likewise, GAUDET (1975) has mentioned that *Cyperus papyrus* shows low mineral concentrations compared to other emergent plants, and that a large part of the variation in nitrogen, phosphorus and potassium obtained between different organs is probably age-related.

In all species of emergent macrophytes related in this study, potassium appears to present the highest values in the dry plant mass.

2. Scirpus californicus

2.1. Coastal Lakes

The mean mineral concentrations of *S.californicus* sampled in some lakes of the Coastal Plain of Rio Grande do Sul are shown in Table 16.

Whereas phosphorus and potassium concentrations in stems were higher than in other parts of the macrophytes of Peixoto Lake, calcium and sodium were slightly higher in the leaves and inflorescences. Generally, the sequence

Table 16: Mineral concentrations (µg/g dry weight) in *S.californicus* collected in some coastal lakes of Rio Grande do Sul during summer. To each lake n=15.

	P	N	Ca	Mg	Na	K	lake
stems	5533	1621	1603	923	2023	35790	Peixoto
	1200	12399	2410	1523	6117	29513	Porteira
	1686	5787	1420	813	3050	11630	Caieira
	1661	3950	1053	747	5050	26813	Emboaba
	1295	3222	1977	917	4757	11817	Palmital
	1187	3635	1277	1463	5970	48633	R.Éguas
	1000	17139	1300	610	2480	17020	Barros
	1905	4964	1203	1113	4960	39430	Tarumã
	1492	1386	1623	1310	6960	13663	B.Solidão
leaves	1146	987	2253	1667	4737	26010	Peixoto
	790	2468	2550	1327	4157	20910	Porteira
	949	4136	1613	613	1803	14463	Caieira
	1178	4342	1777	1893	10623	12637	Emboaba
	812	1616	2137	917	10603	17927	Palmital
	894	961	2363	3467	6193	1963	R.Éguas
	2343	11765	1487	647	3540	18427	Barros
	624	6012	1327	1623	1967	23160	Tarumã
	1417	4087	1763	1403	7367	19543	B.Solidão
inflor.	2937	1250	2310	1107	4617	27293	Peixoto
	2234	6281	1520	1483	4660	13320	Porteira
	2182	4727	1233	883	1300	14443	Caieira
	2264	14762	1167	880	683	11330	Barros
rhiz.	-	-	1930	1006	8540	20310	Porteira
	1177	701	2670	1517	7757	2727	Emboaba

inflor.=inflorescences; rhiz.=rhizomes

of nutrient contents of the plants as a whole showed that potassium (29698 µg/g dry weight) had by far the highest tissue concentration followed by Na>P>Ca>N>Mg.

In Porteira Lake, nitrogen concentrations in the stems was two to six times higher than in the leaves or inflorescences. There was also a slight increase of potassium in the stems and sodium in the rhizomes. Except for phosphorus and nitrogen, the plant in both Porteira and Peixoto lakes showed very similar tendency of concentrating the elements in the stems. Nevertheless, according to the total plant analysis, potassium had the highest tissue concentration (21248 µg/g dry weight) followed by N>Na>Ca>Mg>P in Porteira Lake.

Except for the leaves from Rincão das Éguas Lake, in all bulrushes sampled in the littoral zone of different lakes, potassium appears to accumulate more than the other elements analysed.

Sodium concentrations were higher in the stems of the macrophytes from Caieira Lake, but magnesium was generally low. In Emboaba Lake sodium increased in the leaves, where magnesium and calcium also appeared with slightly higher values compared to the stems. Rhizomes showed the lowest nitrogen accumulations but sodium was expressive. Concentrations of nutrients in the total plant showed that K>Na>N>P>Ca>Mg. Excepting the relation Ca:P, the same tendency was observed in Palmital Lake. High concentrations of potassium and sodium were observed in the leaves of *S.californicus* of this lake, and in the stems of Taruma Lake.

Bulrushes collected in Barros Lake showed the highest nitrogen concentrations (14556 µg/g dry weight). Nevertheless, samples of Porteira Lake showed an increase in nitrogen only in the stems. Considering the general tendency of nutrients in plants collected in Barros Lake, potassium and nitrogen had by far the highest tissue concentration followed by Na>P>Ca>Mg. When sequencial

concentrations of nutrients in the littoral zones are analysed, calcium appears to be the main element that distinguishes both lakes.

In Barros-Solidão Lake nutrients were homogeneously distributed in stems and in the leaves, but nitrogen was slightly higher in the latter. In this lake, as in some of the others, the biomass of the inflorescences was too low to perform the nutrient analysis properly.

Mean nutrient concentrations in *S.fluviatilis* and *S.validus* from wetlands (AUCLAIR, 1979) are generally higher than those found in *S.californicus* from the coastal lakes. However, except for Barros Lake that presented higher nitrogen concentrations than those mentioned by AUCLAIR (op.cit), the bulrushes from the remaining lakes showed higher magnesium and potassium contents.

The sequence of mean mineral concentrations of the bulrushes harvested in the coastal lakes was compared according to their magnitude to obtain the overall measure of agreement among the ranking of the elements. Although the concentrations of nutrients differed from site to site, the Kendall's coefficient of concordance showed that there is an almost perfect correspondence among the mineral contents of *S.californicus* between the different lakes studied ($W=0.788$; $d.f.=5$; $P<0.001$).

Analysis of between-site variance in the nutrient contents of this macrophyte showed that the nitrogen ($F=22.619$; $d.f.=8.57$; $P<0.001$) and magnesium concentrations ($F=7.970$; $d.f.=8,57$; $P<0.001$) differed significantly between most of the lakes, and calcium was the element that differentiated bulrushes from both Barros and Porteira lakes ($F=5.412$; $d.f.=8,57$; $P<0.001$).

2.2. Saco de Tapes

Seasonal variations observed during the summer and winter months in the mineral concentrations of *S.californicus* collected in Saco de Tapes are shown in Table 17. When compared to *S.validus* and *S.fluviatilis* (AUCLAIR, 1979), *S.californicus* presents higher concentrations of magnesium and phosphorus in the tissues. Nevertheless, mineral contents differ between seasons; in winter potassium increases and the values exceed those found by AUCLAIR (op.cit.).

During the summer season, in the southern edge, the rhizomes showed low levels of phosphorus, nitrogen and magnesium. However, the latter accumulated in the leaves and in the inflorescences, whereas nitrogen accumulated in the stems. Sodium and potassium increased in the stems and leaves in the same period. Lower levels of phosphorus and nitrogen were found in the leaves during winter months, but potassium was higher in the stems and sodium in the leaves.

Sodium and potassium were absent in the inflorescences of *S.californicus* collected in the eastern margin during summer. Nevertheless, the leaves showed high phosphorus and low nitrogen contents compared to the stems and inflorescences. During the winter season, phosphorus decreased in the leaves and nitrogen increased in the stems.

In the western edge, where anthropogenic influences are notorious, sodium and potassium were absent in the inflorescences and phosphorus concentrations were high in the leaves as observed in the eastern margin during the summer season. Nitrogen was lower in the stems during summer and increased during the winter months. Nevertheless, sodium was completely absent in the inflorescences during winter and potassium was lower than values found in both stems or leaves.

Table 17: Mean nutrient concentrations (µg/g dry weight) of *Scirpus californicus* collected in Saco de Tapes during summer (su) and winter (w) seasons. To each margin n=54.

	P	N	Ca	Mg	Na	K	margin
stems	1393	9401	1807	943	3398	17664	south-su
	3388	8668	1387	1088	1902	32337	south-w
	4965	9807	2390	1307	3002	18202	east-su
	2654	10729	1824	958	2291	17918	east-w
	1110	6037	1388	828	2474	16603	west-su
	2936	11272	1495	960	3098	29827	west-w
	8716	8548	1500	922	6998	5253	north-su
	1252	12137	1985	1583	9498	20565	north-w
	2098	7309	985	723	1973	12864	norea-w
	1557	9496	1749	807	2315	14090	souwe-w
leaves	1377	5210	2087	1372	4112	18093	south-su
	1156	3595	1612	1469	2948	17616	south-w
	6682	5453	1843	1087	5066	14229	east-su
	867	5137	858	702	7033	17893	east-w
	3740	10606	1554	1077	3292	17908	west-su
	2460	4311	2287	1520	4143	32102	west-w
	14939	10296	2483	1135	1708	3218	north-su
	776	6215	1327	875	748	16420	norea-w
inflor.	1148	4069	1531	1292	574	2533	south-su
	3130	8905	1248	1110	514	10384	south-w
	4437	11048	2601	920	0	0	east-su
	3272	6274	2142	1713	1306	12582	east-w
	1285	10586	1587	987	0	0	west-su
	3045	5135	798	1293	0	12098	west-w

	10968	6383	1250	927	0	2385	north-su
	5311	4741	1543	1862	487	11338	souwe-w
rhiz.	591	1437	1970	652	1882	3327	south-su

inflor.=inflorescence; rhiz.=rhizomes
south = southern edge; east = eastern edge;
west = western edge; north = northern edge;
norea = northeastern edge; souwe = southwest edge.

In the north edge of Saco de Tapes, although the bulrushes showed an increase of phosphorus in the leaves and inflorescences, no sodium was found in the latter during summer. Potassium concentrations in the stems were higher in winter than in summer and, as also observed in the western margin, during winter months nitrogen increased in the stems. The bulrushes present in this margin showed no inflorescences during winter, followed by low leaves biomass.

In the set harvested from the southwest edge of Saco de Tapes during winter, phosphorus and magnesium increased in the inflorescences, whereas nitrogen and sodium showed opposite trends. Leaves biomass were low in this period.

Mean nutrient concentrations of *S.californicus* during the autumn and spring seasons (Table 18) showed between-site and seasonal variations. Phosphorus, magnesium and potassium concentrations in tissues of the bulrushes in autumn are higher than values found by AUCLAIR (1979) for *S.validus* and *S.fluviatilis*, but, in spring, phosphorus concentrations are low.

Table 18: Mean nutrient concentrations (µg/g dry weight) of *Scirpus californicus* collected in Saco de Tapes during autumn (a) and spring (s) seasons. To each margin n=54.

	P	N	Ca	Mg	Na	K	margin
stems	2295	7600	1214	720	2329	17825	west-a
	1914	7299	1229	1214	4428	29548	west-s
	2230	8726	1118	822	2201	20084	norea-a
	1405	10341	1288	1193	3049	24486	norea-s
	1658	6131	1067	557	3221	9098	souwe-a
	1830	9678	2893	1573	5683	21652	souwe-s
	1435	5340	1620	997	2529	24834	east-s
	2534	7916	863	1242	3910	34872	north-s
	1593	12134	2892	2203	2057	42710	espor-s
leaves	3178	6940	1298	758	4298	17295	west-a
	3577	5822	1817	1363	3707	23675	west-s
	3474	4739	1346	1054	5021	20457	norea-a
	998	3882	1819	1333	1694	21517	norea-s
	2633	6902	1559	857	3853	14464	souwe-a
	1696	4979	2637	1763	3085	16349	souwe-s
	1512	8322	1868	1253	1532	13076	east-s
	1772	2878	1695	1527	5492	32633	north-s
inflor.	1939	4768	1480	1604	1994	8305	west-s
	3203	10772	2072	715	0	0	norea-a
	1450	7760	910	1197	1001	7944	norea-s
	964	9488	2727	702	0	147	souwe-a
	-	-	1872	1366	0	11240	east-s
	1956	1344	935	1685	1718	5407	espor-s
rhiz.	2574	5643	2622	1437	837	4028	west-a
	291	680	2598	1210	0	0	west-s

681	1726	4467	1660	0	0	norea-s
-	-	1056	814	0	13076	east-s
572	351	1362	1165	1353	2223	north-s
3659	13409	1158	1623	908	40845	espor-s

inflor.=inflorescence; rhiz.=rhizomes
west = western edge; norea = northeastern edge;
souwe = southwest edge; east = eastern edge;
north = northern edge; espor = "esporão".

In the western margin all nutrients appeared well distributed in the plant, but phosphorus and sodium showed slight increase in the leaves during autumn. The rhizomes presented high magnesium and low sodium and potassium contents. During the spring an increasing accumulation of phosphorus was observed in the leaves, whereas nitrogen as well as sodium and potassium increased in the stems. The rhizomes accumulated calcium and magnesium, but sodium and potassium were completely absent.

Bulrushes of the northeastern margin showed an increased nitrogen in the inflorescences but sodium and potassium were absent during the autumn. In the spring nitrogen increased in the stems and inflorescences, whereas sodium and potassium showed high concentrations in the stems. Both sodium and potassium were totally absent in the rhizomes during the spring, but calcium accumulations were observed.

In the bulrushes from the southwest edge, during the autumn, the inflorescences appear to have the lowest phosphorus and potassium contents, and no sodium was detected. Nitrogen and calcium, however, were higher in this portion than values found in stems or leaves. In the

spring months nitrogen, sodium and potassium increased in the stems, but the inflorescences' biomass were low.

In the same season, bulrushes collected in the eastern margin increased nitrogen in the leaves, and magnesium appeared to accumulate in the leaves and inflorescences. Sodium was completely lacking in the inflorescences and rhizomes.

In the northern margin, however, nitrogen was higher in the stems but calcium was lower during spring season. Phosphorus, nitrogen and potassium decreased in the rhizomes, and inflorescences presented low biomass.

In the "esporão" edge, phosphorus, nitrogen and potassium accumulated in the rhizomes during the spring and sodium decreased. Calcium, magnesium and potassium increased in the stems, but leaves' biomass were very low. In this edge the rhizomes of *S.californicus* showed the highest potassium concentrations compared to all other margins in all different seasons.

Evaluations of the tissue nutrient concentrations in the whole-plant from the southern edge showed that phosphorus, calcium and magnesium did not differ between the summer and winter seasons ($P>0.05$). Nevertheless, leaves and inflorescences in winter differed regarding nitrogen contents ($F=9.263$; $d.f.=5,75$; $P>0.001$). Stems and leaves differed within-plant in both seasons, as well as inflorescences values from winter to summer. Regarding sodium concentrations, inflorescences in both seasons were statistically different from stems and leaves ($F=72.578$; $d.f.=5,66$; $P<0.001$). Potassium in the inflorescences in winter differed from stems and leaves in both periods, but not from inflorescences in summer ($F=6.786$; $d.f.=5,66$; $P<0.001$).

In the western margin sodium showed no between-season differences. Phosphorus in the stems and inflorescences, however, differed from leaves in summer and from the whole plant in winter ($F=26.089$; $d.f.=5,60$; $P<0.001$).

Nitrogen concentrations in the leaves differed between summer and winter ($F=5.879$; $d.f.=5,60$; $P<0.001$). Inflorescences and leaves in winter were significantly different regarding calcium concentrations ($F=6.018$; $d.f.=5,6$; $P<0.001$). Although magnesium contents differentiated stems from leaves in winter ($F=8.488$; $d.f.=5,60$; $P<0.001$), in both seasons no differences were observed between stems. Potassium concentrations in the stems and leaves in winter differed from those of stems and leaves in summer, as well as from the inflorescences in winter ($F=14.929$; $d.f.=4,43$; $P<0.001$).

In the eastern margin magnesium and potassium concentrations showed no significant difference between the seasons in the whole plant ($P>0.05$). Phosphorus concentrations in the bulrushes in summer differed from the stems and leaves in winter, but inflorescences in both seasons did not differ. However, the stems and the inflorescences in winter differed from phosphorus contents in the leaves ($F=26.201$; $d.f.=5,78$; $P<0.001$). Nitrogen concentrations in the stems in winter and summer differed from leaves' contents, and during winter the stems differed also from the inflorescences ($F=23.888$; $d.f.=5,78$; $P<0.001$). Although leaves did not differ between the seasons, the inflorescences showed significant variations in summer and winter. Calcium in the leaves differed from the whole plant in winter ($F=8.579$; $d.f.=5,83$; $P<0.001$). Similar trend was observed for magnesium in the inflorescences ($F=9.407$; $d.f.=5,83$; $P<0.001$). Sodium contents in the stems in winter and summer were significantly different, and the leaves in both seasons differed from the stems in winter ($F=5.937$; $d.f.=4,66$; $P<0.001$).

On the north edge, all nutrients differed between-seasons. Phosphorus showed significant variations in the whole plant in both winter and summer ($F=208.626$; $d.f.=3,20$; $P<0.001$), and leaves and stems in summer

differed in the same set. Regarding nitrogen concentrations the stems did not differ in both seasons. However, the leaves and the inflorescences differed in summer ($F=7.783$; $d.f.=3,20$; $P<0.01$). Calcium concentrations in the stems did not differ in both seasons, but leaves in summer differed from inflorescences and stems ($F=18.694$; $d.f.=3,20$; $P<0.001$). Similar to phosphorus concentrations, magnesium in the whole plant varied between seasons ($F=12.315$; $d.f.=3,20$; $P<0.001$). Calcium concentrations in the stems did not differ in winter and summer, but the leaves were significantly different from the stems in summer ($F=104.730$; $d.f.=2,15$; $P<0.001$). Inflorescences and leaves in summer did not differ regarding potassium concentrations. However, stems in summer differed from stems in the winter ($F=150.156$; $d.f.=3,20$; $P<0.001$).

In the autumn and spring seasons, magnesium concentrations were significantly different in the bulrushes at the western margin of Saco de Tapes ($F=13.618$; $d.f.=4,79$; $P<0.001$). All other elements showed no significant variation between seasons ($P>0.05$).

In the northeastern edge all nutrients differed between the autumn and spring months. Phosphorus was statistically different only in the leaves ($F=5.692$; $d.f.=5,81$; $P<0.001$), but inflorescences in the autumn and in the spring did not differ. Nitrogen concentrations showed no significant differences between the seasons, but the stems in spring differed from the leaves in both periods ($F=9.615$; $d.f.=5,81$; $P<0.001$). Calcium contents differed in the inflorescences in both seasons. Leaves and inflorescences differed in spring, and inflorescences and stems differed in autumn ($F=8.402$; $d.f.=5,81$; $P<0.001$). Regarding magnesium contents, the leaves in spring differed from the stems in autumn ($F=4.681$; $d.f.=5,81$; $P<0.001$). Sodium in the leaves in autumn were statistically different from whole-plant concentrations

in both seasons, and the stems and inflorescences differed in spring ($F=14.234$; $d.f.=4,76$; $P<0.001$). A significant difference was obtained from potassium concentrations in the inflorescence in spring compared to whole-plant contents in both seasons ($F=11.713$; $d.f.=4,76$; $P<0.001$).

Sodium in the plants collected from the southwest edge showed no significant difference between autumn and spring. Phosphorus contents in the leaves were statistically different from the whole plant and from the leaves in spring ($F=7.330$; $d.f.=4,47$; $P<0.001$). Significant differences in the nitrogen concentrations between autumn and spring were not found. However, the stems and the leaves differed in spring ($F=3.822$; $d.f.=4,47$; $P<0.01$). Inflorescences and stems differed in the calcium concentrations during autumn, and the calcium content in the stems varied between both seasons ($F=17.364$; $d.f.=4,52$; $P<0.001$). In the autumn, magnesium differed significantly in stems and leaves ($F=34.351$; $d.f.=4,56$; $P<0.001$). Potassium concentrations in the inflorescences were different from the whole plant in both autumn and spring ($F=17.570$; $d.f.=4,52$; $P<0.001$).

BETWEEN-SEASON VARIATIONS

The analysis of the variability of element concentrations in the tissues of *S.californicus* harvested from the western edge in all seasons showed that calcium ($P>0.25$), sodium ($P>0.50$) and potassium ($P>0.50$) are nutrients whose mean concentrations did not differ between seasons the year round. Nevertheless, phosphorus in summer was completely distinct from those values found in the other seasons ($F=7.122$; $d.f.=3,146$; $P<0.001$) and nitrogen differentiated only bulrushes from summer and

spring ($F=3.764$; $d.f.=3,146$; $P<0.05$). Differences in the mean nitrogen concentrations between spring and autumn were not significant. Magnesium was significantly different in tissues of plants harvested in summer and autumn ($F=23.358$; $d.f.=3,146$; $P<0.001$).

In the same margin, copper accumulations were not significantly different in a between-seasons analysis ($P>0.30$). Nevertheless, zinc differed in bulrushes from spring and summer ($F=3.473$; $d.f.=3,146$; $P<0.05$), and cadmium concentrations were significantly different in autumn compared to winter and spring months ($F=7.537$; $d.f.=3,146$; $P<0.001$). Regarding cadmium, there were similarities in the tissue concentrations in summer and autumn as well as in winter and spring. Lead was found only in the tissues of bulrushes harvested in summer and spring, but the values did not differ between both seasons ($P>0.40$).

BETWEEN-SITE VARIATIONS

Studies carried out in summer demonstrate between-site variations in elemental contents of *S.californicus*, as well as in other emergent macrophytes harvested in some lakes of the Coastal Plain of Rio Grande do Sul. Nutrients and heavy metal concentrations varied within plants in the same site and between plants from different sites in the same season.

The analysis of variance between the south, east, north and west edges of Saco de Tapes showed significant differences in the elements during summer comparisons. Phosphorus differed between these margins ($F=143.348$; $d.f.=3,161$; $P<0.001$) whereas nitrogen differenciated only the southern margin from the others ($F=9.896$; $d.f.=3,161$; $P<0.001$). Calcium concentrations in east and north were

were similar, but eastern was significantly different from the west and south ($F=8.110$; d.f.=3,152, $P<0.001$). Magnesium concentrations in the tissues of the whole plant differed only between southern and western edges ($F=3.196$; d.f.3,152; $P<0.001$). Differences in the sodium concentrations between the south and east were significant ($F=4.701$; d.f.=3,110; $P<0.01$). Excepting the similarities between east and west, between-site differences were significant regarding potassium contents during summer ($F=21.871$; d.f.=3,116; $P<0.001$).

Regarding nutrient concentrations in the tissue of the whole plant, during summer practically all margins differed from each other, although the southern portion of Saco de Tapes presented the greatest difference. This margin, however, was not significantly different from the west, comparing zinc concentrations, but all others were different with regard to this metal ($F=13.308$; d.f.=3,152; $P<0.001$). Copper and cadmium showed similar trends in the system, and were significantly different in the western and eastern margins ($F=4.257$; d.f.=2,135; $P<0.05$ and $F=6.473$; d.f.=2,135; $P<0.01$, respectively). Lead was the only one that did not show any significant between-site variations in summer ($P>0.35$).

In winter some important nutrients showed similar variations throughout the whole plant, between the margins. Differences in phosphorus ($P>0.05$), nitrogen ($P>0.10$), calcium ($P>0.05$) and potassium ($P>0.10$) concentrations were not significant. Nevertheless, magnesium concentrations were statistically different in the northeastern edge compared to the west and the north ($F=4.356$; d.f.=5,119; $P<0.01$), but were similar to the southwest, south and east. Sodium contents in the bulrushes harvested in the north and southwest edges were significantly different ($F=3.503$; d.f.=5,113; $P<0.01$). The difference between the sites, in the last case, is

explained by the salt water influence in the southern portion during this season.

While copper and cadmium presented significant differences between west and east in summer, in the winter months cadmium was responsible for the variations between the southern, western and eastern edges ($F=30.198$; $d.f.=2,81$; $P<0.001$), whereas copper was different only in the east ($F=8.695$; $d.f.=2,81$; $P<0.001$). Differences in zinc contents were not significant in winter ($P>0.30$). Lead, when present in the plant, showed no significant variations ($P>0.30$).

Only altered margins were used to compare between-site variations in autumn: northeast (near a stream which drains water from a swamp to the lagoon), west (near the town of Tapes), and southwest (edge opposite to "esporão", and near an artificial canal of catching water to agricultural purposes). In contrast to observations in winter, phosphorus ($P>0.30$), nitrogen ($P>0.75$) and calcium ($P<0.75$) did not differ in autumn. While in winter potassium did not differ between edges, in autumn the northeast and west were statistically different from the southwest edge ($F=11.393$; $d.f.=2,102$; $P<0.001$), but sodium variations were similar to all of them ($P>0.75$). Magnesium contents in the tissues of plants differentiated northeast and southwest margins ($F=7.576$; $d.f.=2,116$; $P<0.001$). Heavy metal concentrations did not differ between the sites in autumn.

Excepting nitrogen ($P>0.50$), all other mineral nutrients showed differences between the edges in spring. Phosphorus differentiated concentrations of west edge plants from east and northeast, as well as north from northeast ($F=10.926$; $d.f.=5,155$; $P<0.001$). Calcium in bulrushes of southwest was statistically different from all other sites, excepting from "esporão" that is located in an opposite margin. Magnesium differed significantly in southwest and east edges, whereas the "esporão"

differed from east, northeast and west ($F=6.803$; $d.f.=5,160$; $P<0.001$). Sodium in the northeast was statistically different from north and southwest ($F=5.278$; $d.f.=5,155$; $P<0.001$) and potassium differentiated the east margin from all others in spring ($F=19.982$; $d.f.=5,155$; $P<0.001$).

Zinc in spring was the only metal that differentiated the north margin from the others, excepting the east ($F=8.318$; $d.f.=5,155$; $P<0.001$), whereas copper and cadmium showed similar trends ($P>0.05$).

In a between-site and between-season multiple comparison test performed with all data set in all seasons, nitrogen and potassium concentrations did not differ in the macrophytes. Nevertheless, all other elements showed statistically significant variations:

phosphorus	$F=24.667$; $d.f.=18,538$; $P<0.001$;
calcium	$F=7.714$; $d.f.=18,539$; $P<0.001$;
magnesium	$F=16.257$; $d.f.=18,547$; $P<0.001$;
sodium	$F=5.150$; $d.f.=18,474$; $P<0.001$;
zinc	$F=5.729$; $d.f.=18,532$; $P<0.001$;
copper	$F=12.522$; $d.f.=9,383$; $P<0.001$;
cadmium	$F=9.880$; $d.f.=9,383$; $P<0.001$;
lead	$F=6.498$; $d.f.=4,139$; $P<0.001$.

ELEMENT CONCENTRATIONS IN THE BIOMASS

The extent of element concentrations in the biomass of emergent macrophytes has been discussed and analysed by many workers (BJÖRK, 1967; BERNATOWICZ, 1969; DYKYJOVÁ, 1973b, c; VEBER & DYKYJOVÁ, 1973; GAUDET, 1975; KVĚT, 1975; AUCLAIR, 1979; VAN DER LINDEN, 1980; GRANÉLI, 1983, 1985; GRANÉLI et al., 1983). A variety of experiments have also been done on a range of floating-leaved and submerged-leaved macrophytes (DENNY, 1972; REJMANKOVÁ,

1973a,b, 1975a,b, 1976, 1982; BARKO & SMART, 1980; ROGERS & BREEN, 1980; CARY & WEERTS, 1983).

Mean mineral concentrations in the biomass of a single species, however, vary greatly according to climate, season, geology and other related factors, as well as to the interspecific variations of the macrophytes.

Variations in mean mineral content of three emergent macrophytes (*Typha domingensis*, *Cyperus giganteus* and *Zizaniopsis bonariensis*) collected in coastal lakes of Rio Grande do Sul, and of a shoreline species (*Echinodorus grandiflorus*) collected in two different lakes are shown in Table 19.

Table 19: Comparison of mean element concentrations in four aquatic plant species (% dry weight) collected in summer in some lakes of the Coastal Plain of Rio Grande do Sul. To each species n=45.

Element	*T.dom.*	*C.gig.*	*Z.bon.*	*E.gra.*[1]	*E.gra.*[2]
P	0.18	0.04	0.14	0.28	0.57
N	0.58	0.23	0.29	0.85	1.33
Ca	0.69	0.24	0.15	0.77	0.64
Mg	0.31	0.12	0.06	0.47	0.25
Na	0.32	0.36	0.52	0.78	0.44
K	3.14	1.32	1.36	5.17	6.33
Zn	0.003	0.004	0.001	0.005	0.004
Cu	n.d.	n.d.	n.d.	0.001	0.001

n.d.=not detectable in the biomass

T.dom.= *Typha domingensis*

C.gig.= *Cyperus giganteus*

Z.bon.= *Zizaniopsis bonariensis*

E.gra.[1]= *Echinodorus grandiflorus* (Porteira Lake)

E.gra.[2]= *Echinodorus grandiflorus* (Saco de Tapes)

Potassium showed the highest concentrations in biomass of all species and *C.giganteus* among the others was the species with the lowest nutrient concentrations followed by *Z.bonariensis* and *T.domingensis*. GAUDET (1975) had already mentioned similar trends to *C.papyrus* in african swamps. Mean concentrations in tissues of *T.domingensis* lie within the range obtained by BOYD & HESS (1970) for *T.latifolia*, but are higher than values of potassium, calcium and magnesium mentioned by DYKYJOVÁ (1973b) for the latter and, except for calcium, for *T.angustifolia* in temperate zones. VEBER & DYKYJOVÁ (1973) stated that *T.latifolia*, has greater demands for potassium but the sorption is limited by the increasing concentration of nitrogen in the substratum.

S.californicus collected in the coastal lakes also presented important variations in the element concentrations related to the plant aboveground biomass (Table 20). Barros Lake's emergents showed the highest nitrogen contents, whereas potassium was higher in macrophytes of Tarumã and Rincão das Éguas lakes.

Except for the high nitrogen contents of bulrushes from Barros Lake and the low concentrations of phosphorus and nitrogen at the others, the nutrient contents related to aboveground biomass of bulrushes collected in the coastal lakes are generally within the range quoted by DYKYJOVÁ (1973b, c) for *Bolboschoenus* (*Scirpus*) *maritimus* and *Schoenoplectus* (*Scirpus*) *lacustris*.

Mean variations in the nutrient and metal concentrations in the biomass of bulrushes harvested in Saco de Tapes showed between-site differences (Table 21).

Bulrushes of the north margin of Saco de Tapes showed biomass as high as those of the south edge, but the mean concentration of phosphorus in the total dry mass was higher in the north than in south, east or even in west edges, and those plants harvested in the coastal lakes.

Table 20: Comparison of mean element concentrations (% dry weight) of *S.californicus* collected in summer at different coastal lakes of Rio Grande do Sul (lakes are disposed in a north-south sequence). To each lake n=45.

Lake	P	N	Ca	Mg	Na	K	Zn	Cu
Palm	0.10	0.24	0.21	0.09	0.77	1.49	0.002	n.d.
Caie	0.16	0.49	0.14	0.08	0.20	1.35	0.003	n.d.
Peix	0.32	0.13	0.21	0.12	0.38	2.97	0.005	0.001
Embo	0.14	0.41	0.14	0.13	0.78	1.97	0.003	n.d.
Barr	0.19	1.46	0.13	0.07	0.22	1.56	0.003	n.d.
REgu	0.10	0.23	0.18	0.25	0.61	2.53	0.003	0.001
Port	0.14	0.70	0.22	0.14	0.50	2.12	0.003	n.d.
BSol	0.14	0.27	0.17	0.14	0.72	1.66	0.001	n.d.
Taru	0.13	0.55	0.13	0.14	0.35	3.13	0.002	0.002

n.d.=not detectable in the biomass
Palm=Palmital; Caie=Caieira;
Peix=Peixoto; Embo=Emboaba;
Barr=Barros; REgu=Rincão das Éguas;
Port=Porteira; BSol=Barros Solidão;
Taru=Tarumã.

Table 21: Comparison of mean element concentrations (% dry weight) of *S.californicus* collected in summer at four sites in Saco de Tapes.

Element	south n=45	east n=54	north n=18	west n=48
P	0.13	0.54	1.15	0.18
N	0.62	0.88	0.84	0.89
Ca	0.18	0.23	0.17	0.15
Mg	0.12	0.11	0.10	0.10
Na	0.27	0.41	0.43	0.28
K	1.28	1.62	0.36	1.71
Zn	0.003	0.001	0.005	0.002
Cu	n.d.	n.d.	n.d.	n.d.

n.d.=not detectable in the biomass

TISSUE ELEMENT PATTERNS

The mean tissue nutrient and heavy metal concentration varied greatly depending on the element (Table 22) and on the aquatic plant.

Between-species coefficient of variation differences were greatest in phosphorus and least in magnesium. In terms of plant physiological needs and retention (AUCLAIR, 1979) this nutrient is much more regulated in the system.

E.grandiflorus appeared to have a greater ability to concentrate more nutrients than other plants (Fig. 25). Species from both Saco de Tapes and Porteira Lake showed the greatest concentrations of ash, phosphorus, nitrogen, potassium, and also zinc and copper.

Table 22: Mean element concentrations (μg/g dry weight) in shoreline species and emergent macrophytes. Concentrations are averaged from samples taken in the summer season. To each species n=45.

	P	N	Ca	Mg	Na	K	Zn	Cu	Cd	ash	total
E.grandiflorus1	5680	13326	6378	2505	4448	63290	43.86	10.14	0.29	43.22	95682
E.grandiflorus2	2756	8529	7661	4707	7788	51707	52.67	10.57	0.48	63.06	83211
T.domingensis	2042	5856	6948	3072	3185	31377	29.70	8.35	0.31	34.03	52518
C.giganteus	429	2277	2423	1190	3603	13200	39.59	4.89	0.64	40.70	23168
Z.bonariensis	1391	3298	1336	618	5242	15935	9.07	2.33	0.48	18.90	27833
element mean	2460	6657	4949	2418	4853	35102	34.98	7.26	0.44	39.98	56482
coefficient of variation	81.0	66.8	57.9	6.0	37.5	62.6	47.7	48.9	32.6	40.0	57.3

E.grandiflorus1=from Saco de Tapes
E.grandiflorus2=from Porteira Lake

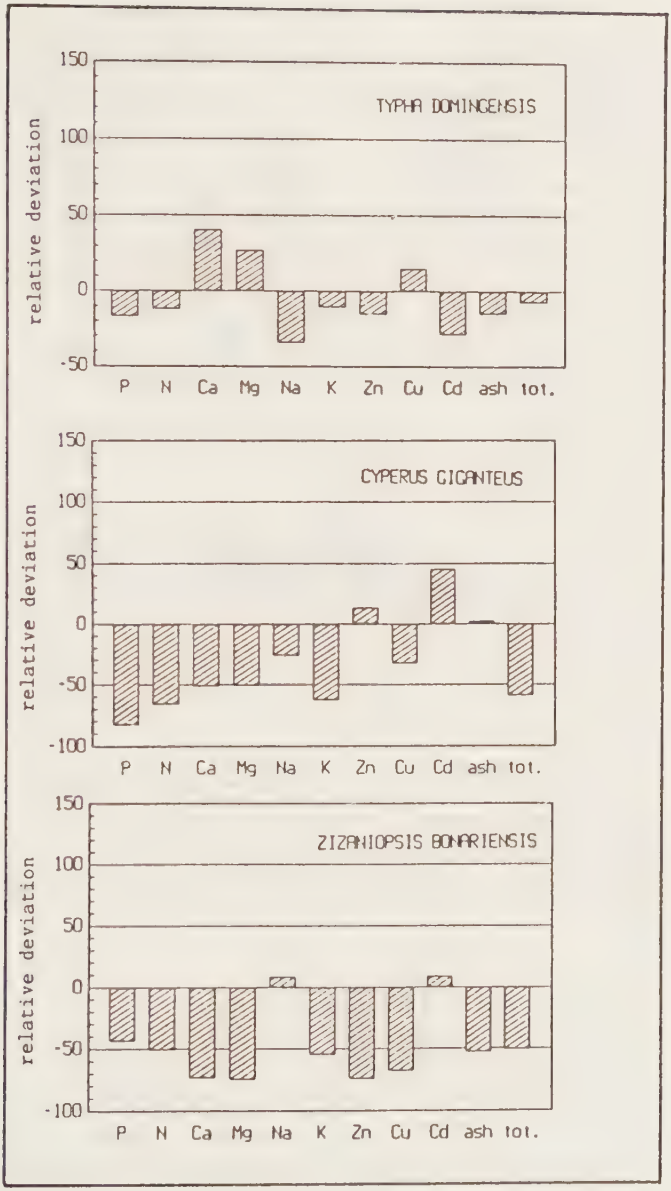

TYPHA DOMINGENSIS
relative deviation
150
100
50
0
-50
P N Ca Mg Na K Zn Cu Cd ash tot.
CYPERUS GIGANTEUS
relative deviation
150
100
50
0
-50
-100
P N Ca Mg Na K Zn Cu Cd ash tot.
ZIZANIOPSIS BONARIENSIS
relative deviation
150
100
50
0
-50
-100
P N Ca Mg Na K Zn Cu Cd ash tot.

Fig.25

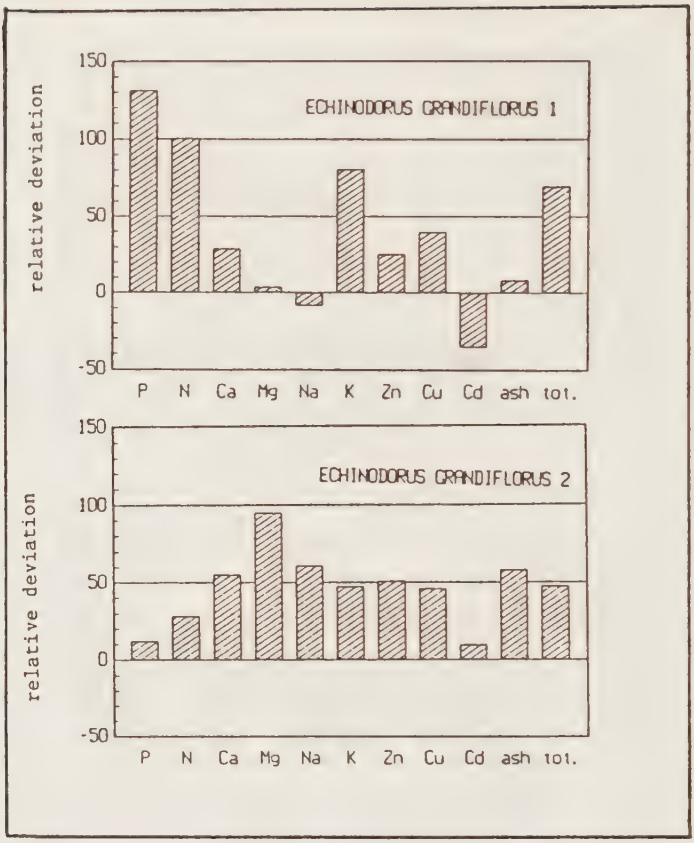


Figure 25: Percent deviation of the mean element concentrations of emergent macrophytes and a shoreline species from the littoral zone of south-brazilian coastal lakes.

T.domingensis presented nutrient levels near the mean and was relatively balanced. *Z.bonariensis* had tissue concentration mostly below average. Among all species, the highest accumulation in cadmium was attributable to *C.giganteus*.

The correlation coefficients between tissue elements were significant to almost all the cases except for sodium and cadmium (Table 23). Tissue potassium has the highest proportion of the total original variance of each element accounted for by the first axis of the principal component analysis (Fig. 26). This indicates that potassium variations between the species are more similar to the variation of the whole nutrients than that of any other element. Interspecies variation in tissue potassium was also found in a wetland community (AUCLAIR, 1979). Therefore, in cases where a model or prediction of tissue nutrients is required, potassium as a single element would be an important component.

Table 23: Simple correlation coefficients based on tissue element variations of shoreline species and emergent macrophytes from the coastal lakes.

	P	N	Ca	Mg	Na	K	Zn	Cu	Cd	ash	total
P	1.0	.98**	.59	.40	.16	.93*	.41	.70	-.77	.32	.91*
N		1.0	.71	.55	.26	.98**	.55	.82*	-.72	.48	.97**
Ca			1.0	.93*	.28	.80	.69	.96**	-.61	.71	.83*
Mg				1.0	.55	.70	.73	.89*	-.34	.83*	.74
Na					1.0	.40	.34	.30	.16	.58	.42
K						1.0	.65	.89*	-.65	.63	.99***
Zn							1.0	.82*	-.00	.95**	.66
Cu								1.0	-.54	.80	.91*
Cd									1.0	.06	-.65
ash										1.0	.65
total											1.0

P<0.05 (*); P<0.01 (**); P<0.001(***).

The principal component analysis based on the correlation among tissue elements indicated a tendency of clustering on both positive poles of the first and second axis (Fig. 26), except for cadmium that remains in the

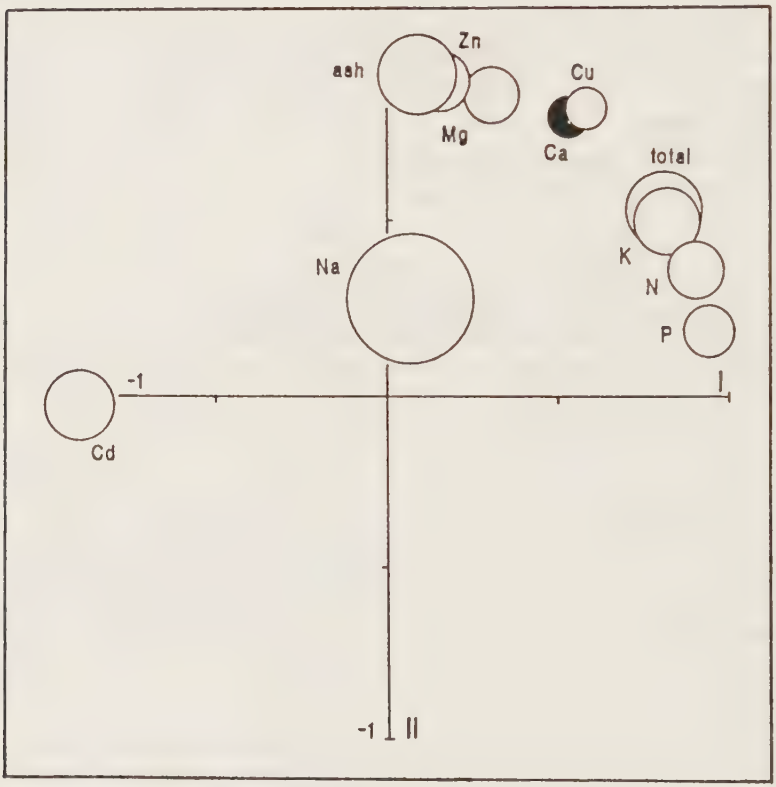


Figure 26: Principal components analysis of ash, total, and individual nutrients and heavy metals in aboveground tissue of emergent macrophytes. Magnitude of variables on component III is represented by circle diameter; closed circles are negative values and open circles positive values.

negative pole of the first axis. The Component I accounted for 68.7% of the total variation. Phosphorus, nitrogen and potassium showed a similar pattern of increasing and decreasing concentrations among the tissue nutrients of the aquatic plants investigated. Calcium, magnesium, zinc and copper grouped on the second axis, and accounted for 18.7% of the total variation. Sodium, which contributed with 7.4% of the total element variation, occurred alone in the third axis.

The species model based on principal component analysis (Fig. 27.A) indicates that macrophytes show different patterns in the littoral zone. Tissue phosphorus concentration plotted in a factor space showed a decreasing level from *E.grandiflorus* (from Saco de Tapes) through *C.giganteus* and *Z.bonariensis* (Fig. 27.B). This tendency was also typical of nitrogen and potassium. Tissue magnesium concentration showed the same tendency as calcium (Fig. 27.C) with decreasing levels from *E.grandiflorus* and *T.domingensis* through *C.giganteus* and *Z.bonariensis*. Values for sodium were high in *E.grandiflorus* from Porteira Lake (Fig. 27.D) and low in *T.domingensis* and *C.giganteus*. Zinc concentrations were greatest in *E.grandiflorus* and very low in *Z.bonariensis* (Fig. 27.E).

The mean coefficient of variation in *S.californicus* tissue elements varied greatly when the nine sampled lakes are analysed together (Table 24). Differences between the bulrushes were greatest in nitrogen and copper and least in calcium. Potassium and zinc showed a low mean coefficient of variation suggesting that both, and tissue calcium, were more regulated in the coastal system than the other elements.

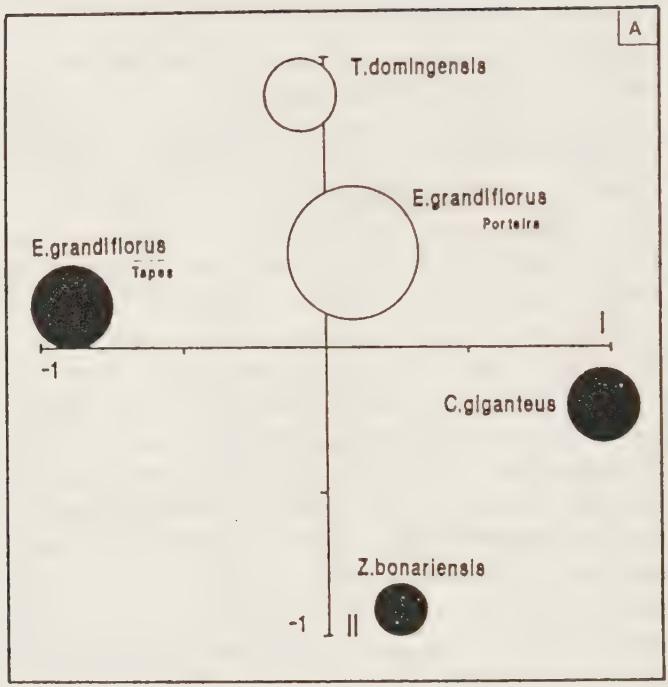
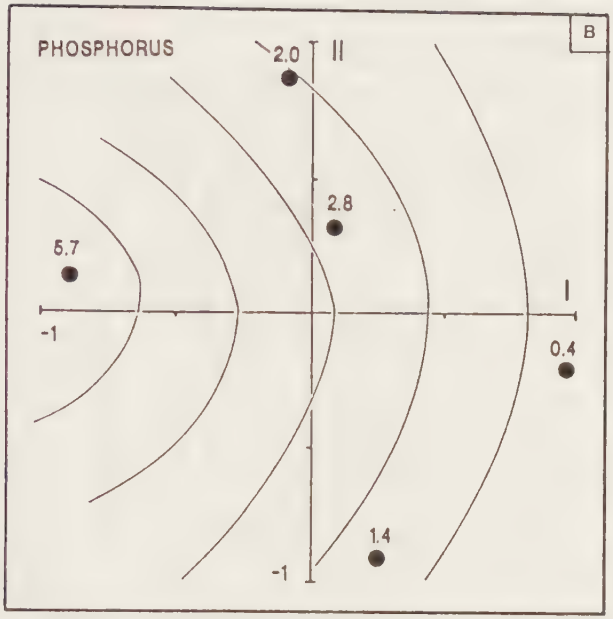
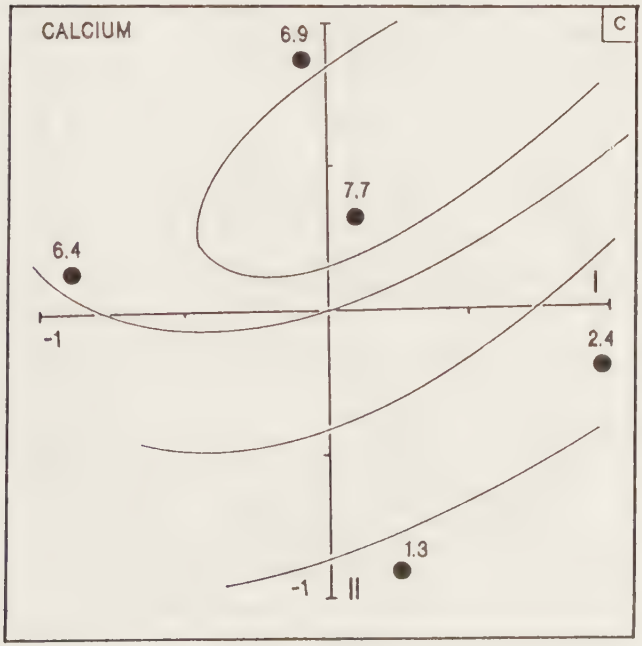
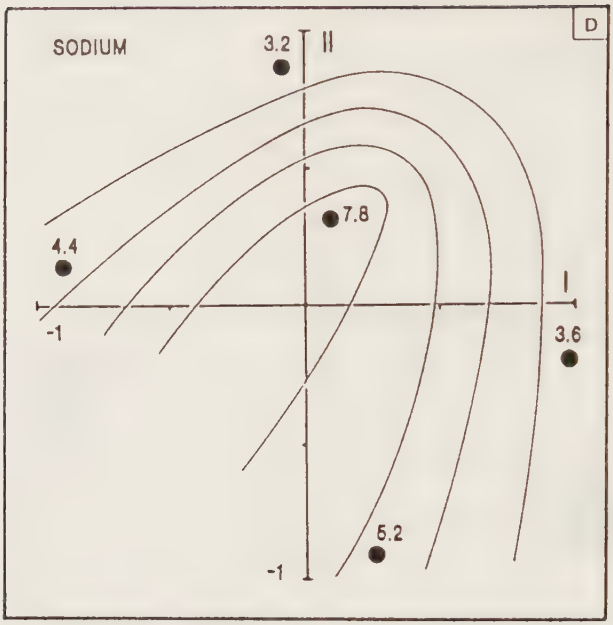


Figure 27: A. Principal components analysis based on species mean tissue element and heavy metal concentrations. Magnitude of variables on component III is represented by circle diameter; closed circles are negative values and open circles positive values. B. tissue phosphorus; C. tissue calcium; D. tissue sodium, and E. tissue zinc mean concentrations of each aquatic macrophyte superimposed on components I and II.


PHOSPHORUS
B
2.0
II
2.8
5.7
I
-1
0.4
1.4
-1


CALCIUM
C
6.9
7.7
6.4
I
-1
2.4
1.3
-1
II


SODIUM
D
3.2
II
7.8
4.4
I
-1
3.6
5.2
-1

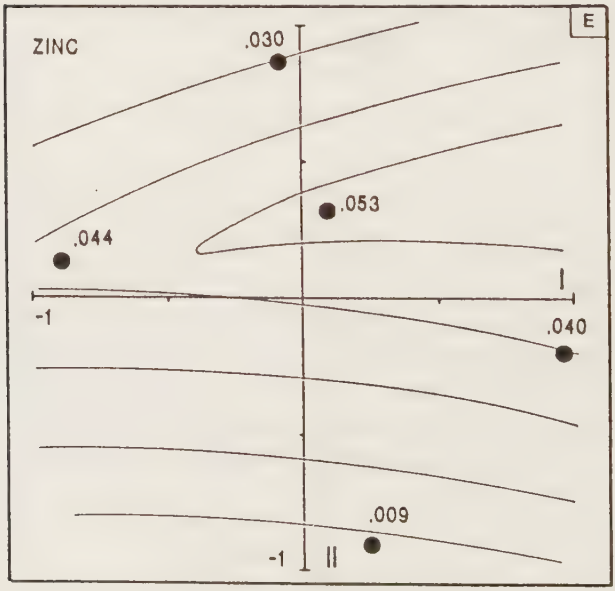

ZINC
E
.030
.053
.044
I
-1
.040
.009
-1
II

Table 24: Mean element concentrations (μg/g dry weight) in *S.californicus* collected in the coastal lakes. Concentrations are averaged from samples taken in the summer season. To each lake n=45.

	P	N	Ca	Mg	Na	K	Zn	Cu	Cd	ash	total
Palmital	1054	2419	2057	917	7680	14872	24.19	3.77	1.07	20.13	29027
Caieira	1605	4883	1422	770	2051	13512	31.30	2.75	1.23	5.63	24279
Peixoto	3205	1283	2056	1232	3792	29698	46.98	6.80	1.47	35.40	41322
Barros	1869	14556	1318	712	2234	15592	29.05	4.45	1.31	29.02	36316
Emboaba	1419	4146	1415	1320	7837	19725	30.81	4.78	1.62	17.04	35899
R.Éguas	1040	2298	1820	2465	6082	25298	34.12	14.37	2.03	18.72	39054
Porteira	1408	7049	2160	1444	4978	21248	26.16	4.86	1.44	44.56	38320
B.Solidão	1454	2736	1693	1357	7163	16603	12.83	2.33	0.61	16.23	31023
Tarumã	1265	5488	1265	1368	3463	31295	24.65	19.50	1.78	23.61	44190
element mean	1591	4984	1689	1287	5031	20871	28.90	7.07	1.40	23.37	35492
coeff.of variation	41.3	80.7	20.6	40.4	45.1	31.4	31.7	83.2	29.7	49.3	17.8

S.californicus from Barros Lake had by far the greatest concentrations of nitrogen (Fig. 28.I), but other elements were below average. Tissue phosphorus was high in Peixoto Lake (Fig. 28.D) but nitrogen was very low. Copper and cadmium accumulations were observed in the bulrushes of Rincao das Eguas and Taruma lakes (Fig. 28.F and G). Bulrushes collected in Emboaba Lake (Fig. 28.C) also showed some cadmium accumulation. The poorest tissue element concentration seems to occur in the aboveground parts of bulrushes harvested in the Caieira and Barros-Solidao lakes (Fig. 28.B and H). Except for zinc in the first and sodium in the latter, all other elements were very weakly represented.

The great variability of tissue elements between bulrushes collected in the coastal lakes (Fig. 29) are clearly observed in the relative deviation of element concentration from the plant mean. High deviations in tissue elements were typical to all lakes. Nevertheless, except for Palmital Lake, a slight decrease in tissue phosphorus in a north-south gradient is observed. The opposite occurred for tissue magnesium, that increased in the same gradient. Although the total elements in the aboveground tissue of *S.californicus* varied within 30% limits of the mean, the ash content differed markedly in all lakes.

The mean element concentrations of *S.californicus* from the coastal lakes are within the range of those from *T.domingensis*, *C.giganteus* and *Z.bonariensis*. However,

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Figure 28: Percent deviation of the mean element concentrations of *S.californicus* from the littoral zone of coastal lakes. A. Palmital Lake; B. Caieira Lake; C. Emboaba Lake; D. Peixoto Lake; E. Porteira Lake; F. Rincao das Éguas Lake; G. Taruma Lake; H. Barros-Solidao Lake; and I. Barros Lake.

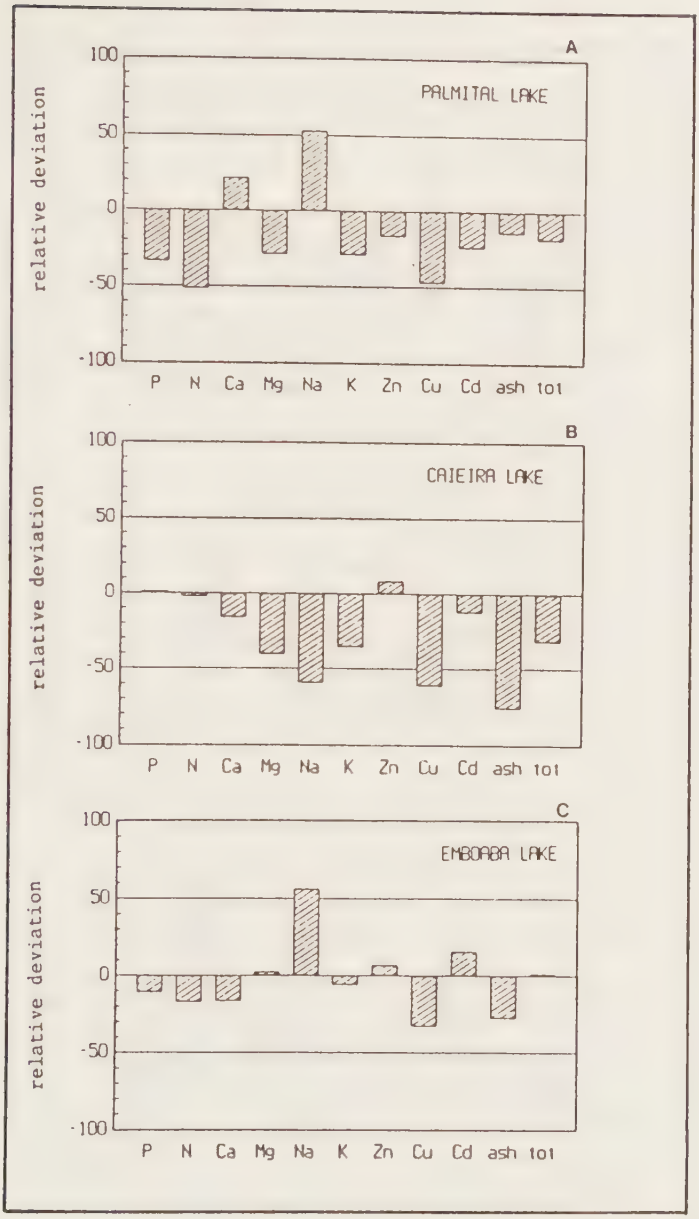

A
PALMITAL LAKE
relative deviation
100
50
0
-50
-100
P N Ca Mg Na K Zn Cu Cd ash tot
B
CAIEIRA LAKE
relative deviation
100
50
0
-50
-100
P N Ca Mg Na K Zn Cu Cd ash tot
C
EMBOABA LAKE
relative deviation
100
50
0
-50
-100
P N Ca Mg Na K Zn Cu Cd ash tot

Fig. 28

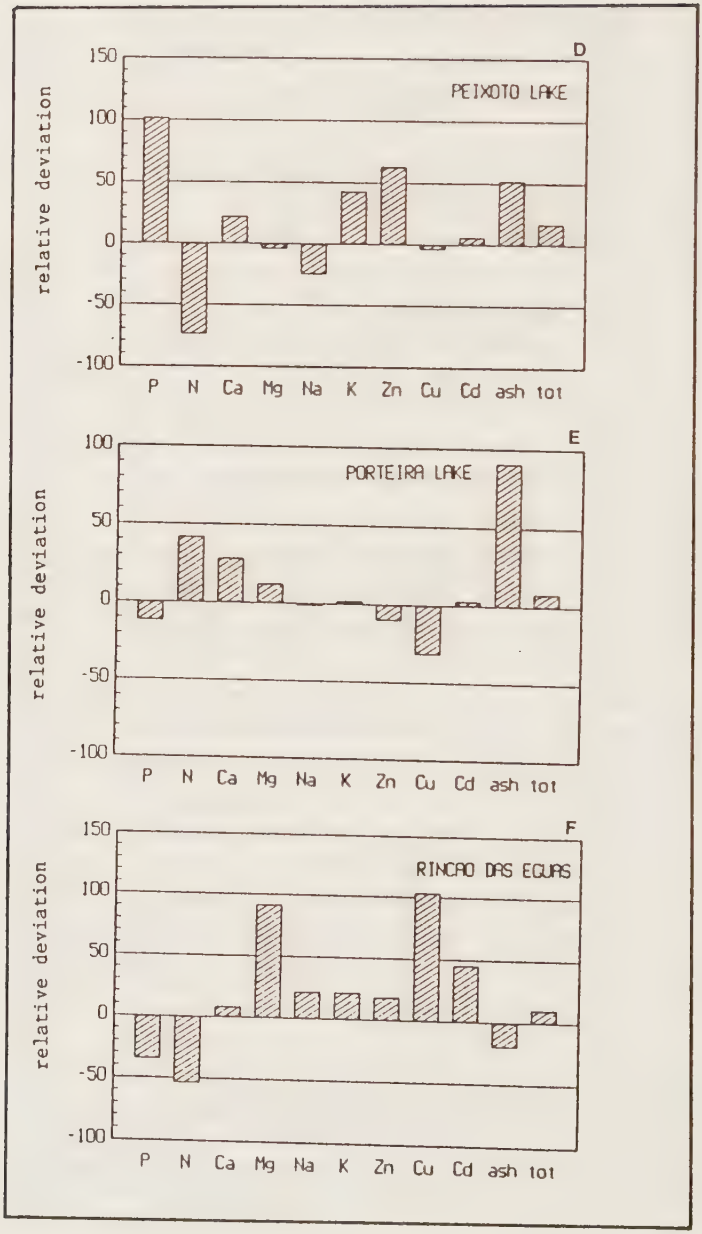

D
PEIXOTO LAKE
relative deviation
150
100
50
0
-50
-100
P N Ca Mg Na K Zn Cu Cd ash tot
E
PORTEIRA LAKE
relative deviation
100
50
0
-50
-100
P N Ca Mg Na K Zn Cu Cd ash tot
F
RINCAO DAS EGUAS
relative deviation
150
100
50
0
-50
-100
P N Ca Mg Na K Zn Cu Cd ash tot

Fig.28

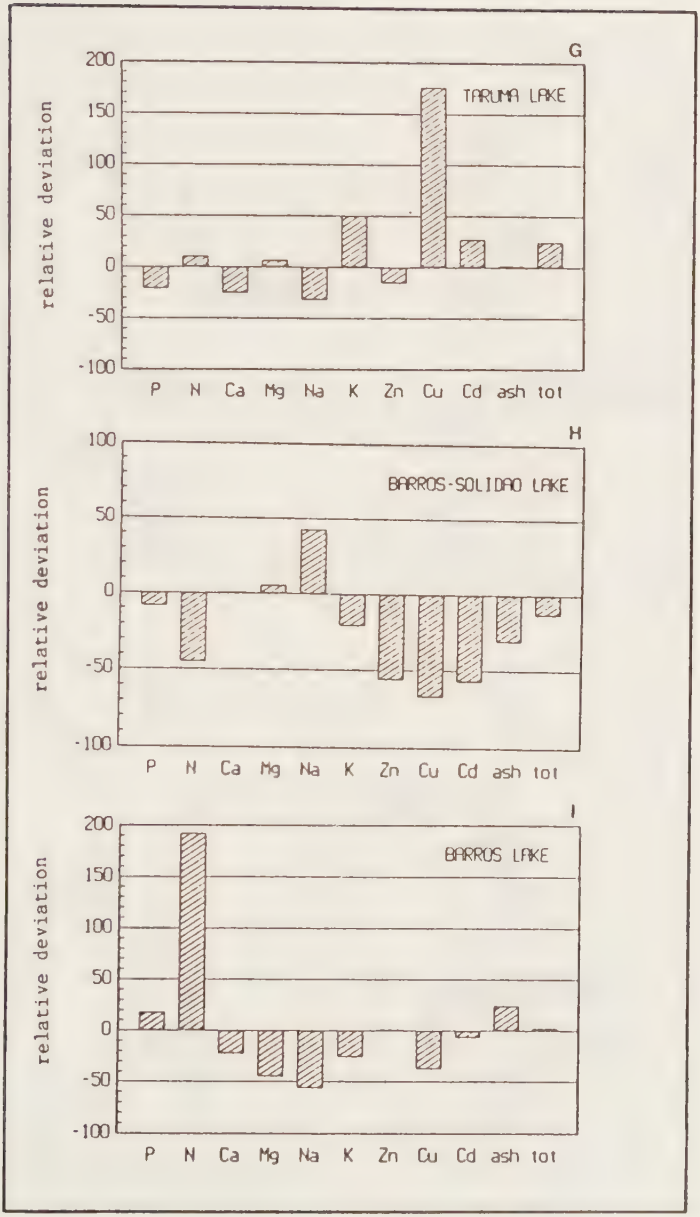
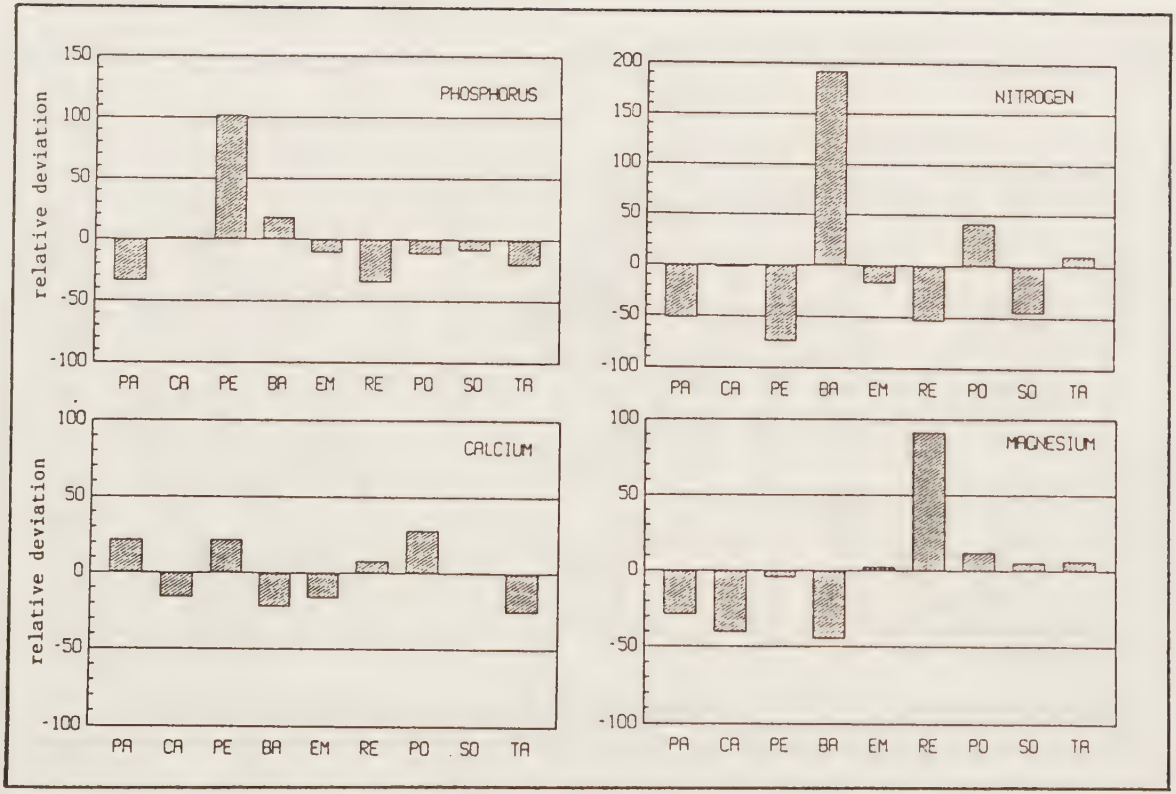
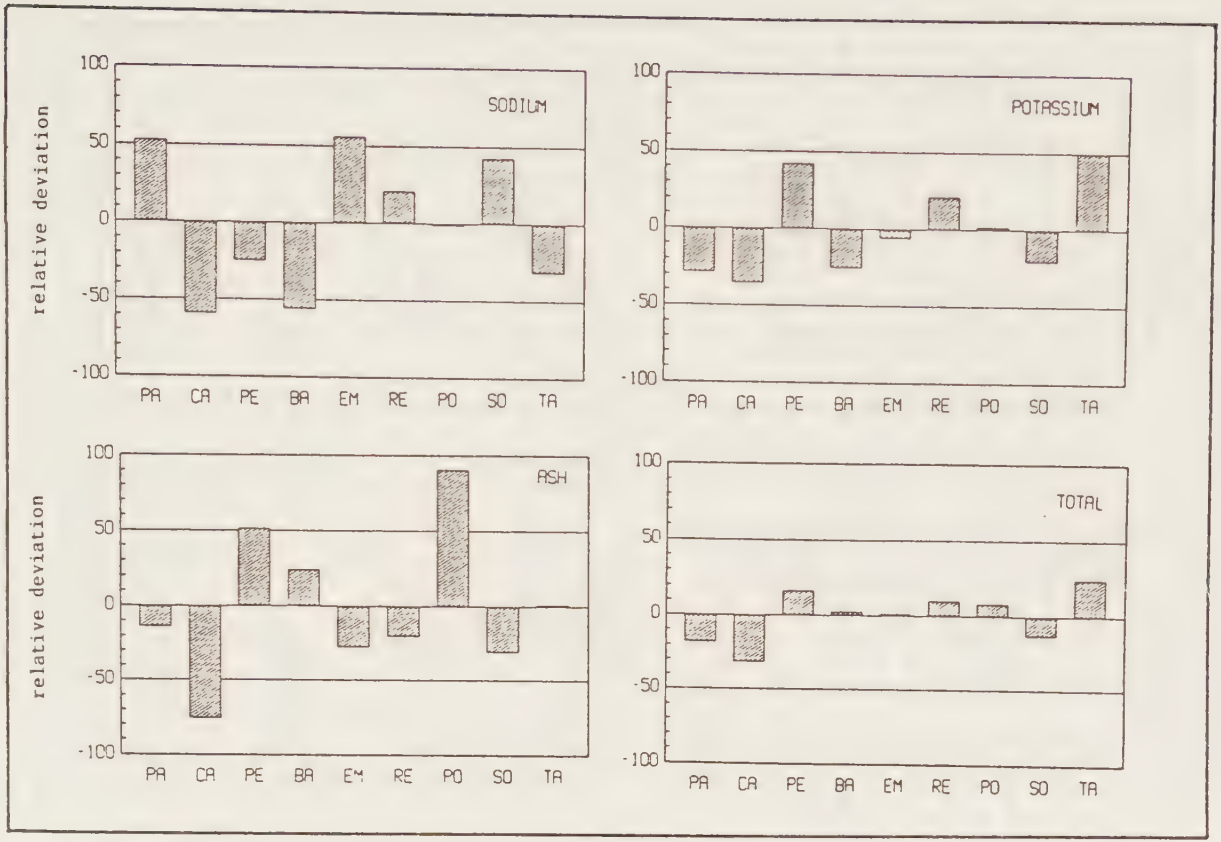

G
TARUMÃ LAKE
relative deviation
200
150
100
50
0
-50
-100
P N Ca Mg Na K Zn Cu Cd ash tot
H
BARROS-SOLIDÃO LAKE
relative deviation
100
50
0
-50
-100
P N Ca Mg Na K Zn Cu Cd ash tot
I
BARROS LAKE
relative deviation
200
150
100
50
0
-50
-100
P N Ca Mg Na K Zn Cu Cd ash tot

Fig.28



Coastal Lakes

Fig. 29



Coastal Lakes

Fig. 29

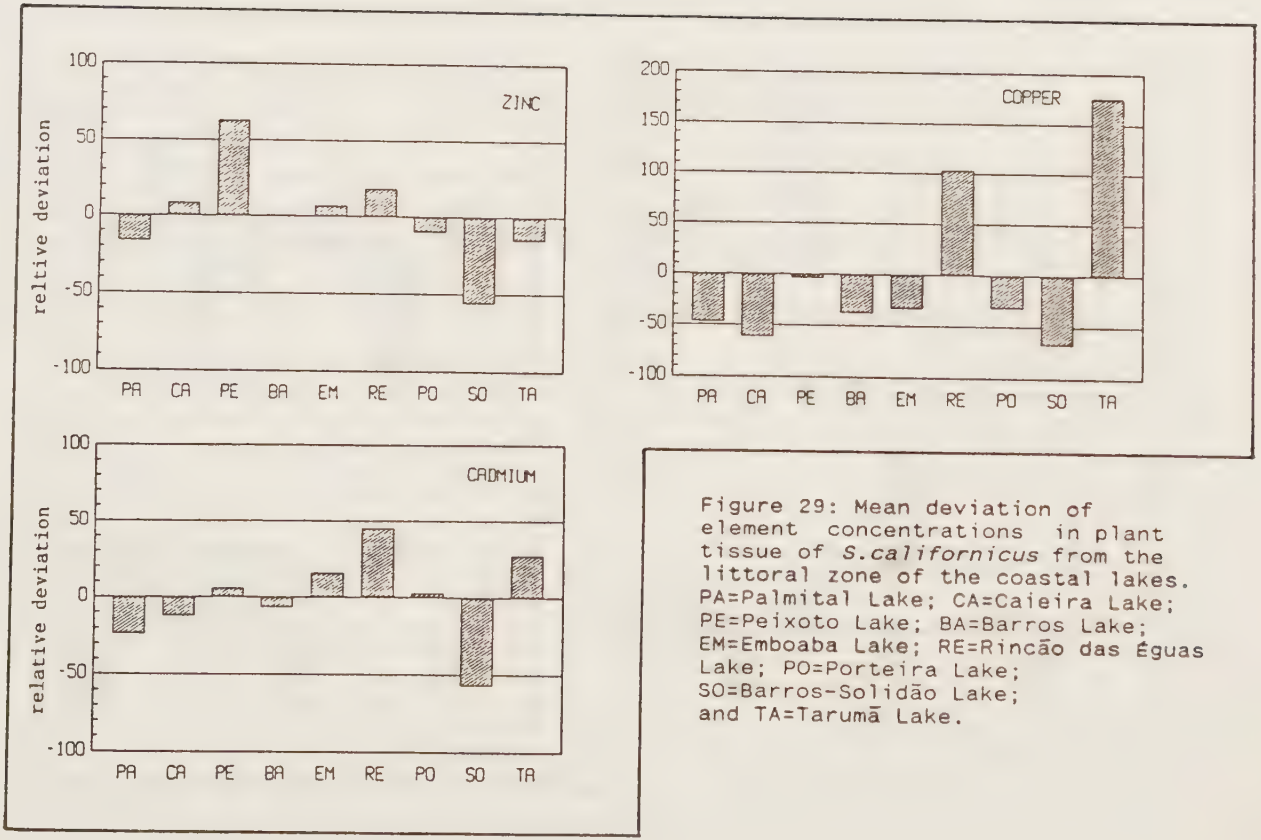


Figure 29: Mean deviation of element concentrations in plant tissue of *S.californicus* from the littoral zone of the coastal lakes. PA=Palmital Lake; CA=Caieira Lake; PE=Peixoto Lake; BA=Barros Lake; EM=Emboaba Lake; RE=Rincão das Éguas Lake; PO=Porteira Lake; SO=Barros-Solidão Lake; and TA=Tarumã Lake.

cadmium seems to be more accumulated in *Scirpus* than in other emergents from this region, including the shoreline species *E.grandiflorus* which appears as a great nutrient accumulator.

Correlation coefficients between tissue elements of *S.californicus* were significant only between phosphorus, potassium, copper and cadmium (Table 25). Among individual elements, potassium showed the higher proportion of the total original variance accounted for by the Component I of the principal component analysis (Fig. 30). Tissue potassium, also referred to as the emergents and shoreline species investigated in this work, constitutes the single element that could contribute advantageously to the establishment of models dealing with tissue nutrients.

Table 25: Simple correlation coefficients based on aboveground tissue nutrient concentrations in *S.californicus* from nine lakes of the Coastal Plain.

	P	N	Ca	Mg	Na	K	Zn	Cu	Cd	ash	tot.
P	1.0										
N	-.03	1.0									
Ca	.17	-.46	1.0								
Mg	-.28	-.43	.26	1.0							
Na	-.42	-.54	.37	.38	1.0						
K	.31	-.30	.09	.53	-.12	1.0					
Zn	.69*	-.14	.19	.10	-.35	.44	1.0				
Cu	-.20	-.11	-.24	.56	-.15	.80**	.15	1.0			
Cd	-.06	-.01	-.12	.57	-.16	.67*	.57	.75*	1.0		
ash	.38	.26	.52	.08	-.12	.42	.25	.07	.18	1.0	
tot	.25	.07	.02	.47	-.10	.89***	.34	.72*	.66*	.63*	1.0

P<0.05 (*); P<0.01 (**); P<0.001(***).

The element clustering on the positive pole of the first component of the principal components analysis accounted for only 37.3% of the total variation (Fig. 30). This suggests that bulrushes did not show a common pattern of increasing or decreasing concentrations, at

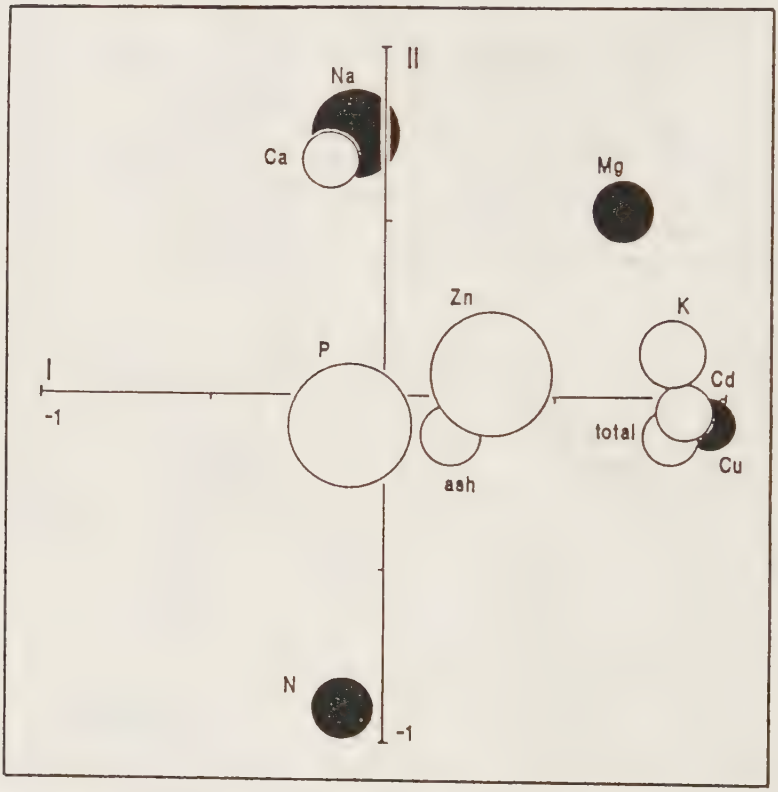


Figure 30: Principal components analysis of ash, total, and individual nutrients and heavy metals in aboveground tissue of *S.californicus*. Magnitude of variables on component III is represented by circle diameter; closed circles are negative values and open circles positive values.

least regarding the first axis when cadmium and copper were present. Such results may reflect the heterogeneity of the littoral zone of the different coastal lakes based on their type, localization and basin geology. Sodium and calcium that grouped together in the positive pole of the second component, opposite to nitrogen, showed the higher proportion of the total original variance that accounted for 21.7%. Phosphorus and zinc showed a tendency to grouping on the third component, that accounted for 18.2% of the total variance. Ash contents were positioned alone in the fourth component, which accounted for 11.0% of the total variance in the above ground tissue of *S.californicus*.

The concentration of individual elements in the bulrushes, was not essentially related to sediment element concentrations (Table 26). Sediment nutrients that affected tissue elements were especially potassium and phosphorus. Sediment potassium had the highest correlation with tissue calcium followed by sediment phosphorus with tissue zinc. Cadmium in the sediment showed high correlation to tissue magnesium and a weak relation (near the margin of significance) with tissue cadmium concentrations.

Moreover, the bulrushes present in the coastal lakes were not nutrient-limited, since no correlation was found between biomass and sediment nutrients (Table 26).

Differences in the uptake and utilization of nutrients by plants are shown by different patterns between the species (AUCLAIR, 1979). A bulrush model to the coastal lakes based on principal components analysis (Fig. 31) shows that although dealing with the same species, a notorious separation occurs between them. Bulrushes from Peixoto Lake showed the higher differentiation, and occurred alone in the Component IV of the PCA that accounted for 13.2% of the total variance. The level of tissue potassium plotted in a three factor space

Table 26: Simple correlation coefficients relating sediment and tissue element concentration of *S.californicus* in the coastal lakes.

tissue element	sediment element content									
	P	N	Ca	Mg	Na	K	Zn	Cu	Cd	Pb
P	.590	-.035	-.099	-.099	-.084	-.049	-.097	.054	-.300	.127
N	-.267	.162	.208	.208	.178	.193	.043	.170	-.254	-.196
Ca	-.063	-.054	-.060	-.089	-.063	.940***	.267	-.259	-.110	.596+
Mg	-.146	.022	.026	.097	.115	-.102	.164	-.076	.852**	-.267
Na	-.458	-.099	-.086	-.023	-.013	.320	.083	-.228	.163	-.022
K	.062	-.031	-.073	.019	.042	-.156	-.119	.115	.262	-.310
Zn	.691*	-.027	-.084	-.105	-.080	.080	.297	.068	.234	.376
Cu	-.228	-.215	-.216	-.141	-.134	-.195	-.242	-.063	.464	-.377
Cd	.109	.026	.017	.042	.062	.177	.314	.077	.587+	.072
ash	-.043	.601+	.586+	.695*	.693*	-.149	.390	.713*	-.140	-.496
total	-.209	.059	.042	.168	.181	.039	-.036	.174	.217	-.476
biomass	.134	-.236	-.236	-.289	-.300	-.609+	-.529	-.111	-.008	-.141
height	-.357	-.424	-.424	-.365	-.369	-.449	-.764**	-.298	.018	-.492

0.10>P>0.05(+); P<0.05(*); P<0.01(**); P<0.001(***).

(Fig. 31.A) denotes the great variability of this element. A weak tendency of increasing potassium in a gradient from north to south in the coastal lakes was observed, disturbed only by the inclusion of Barros-Solidão Lake. Bulrushes from Caieira Lake presented the

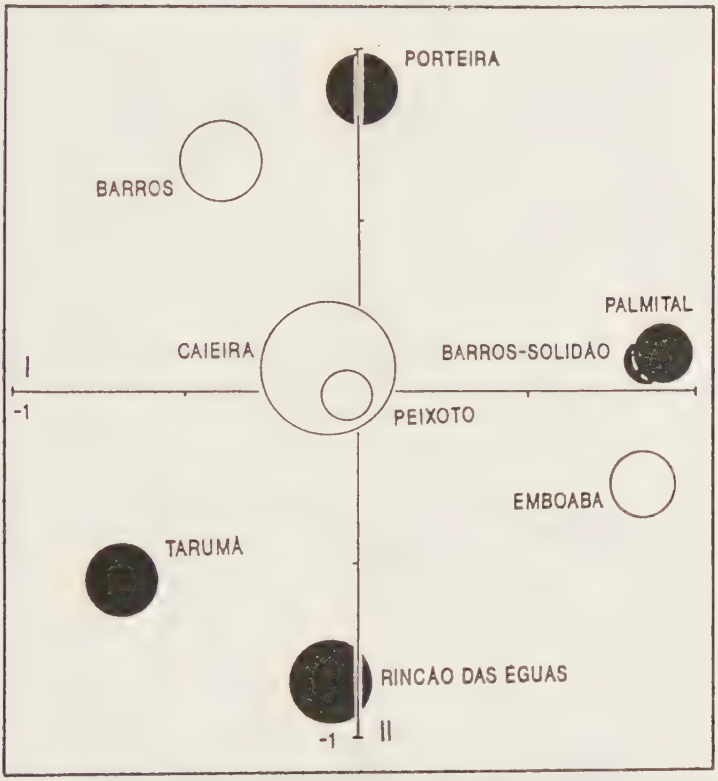
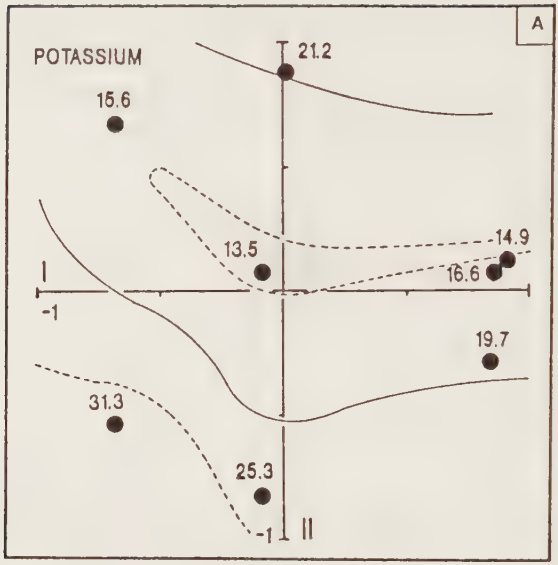
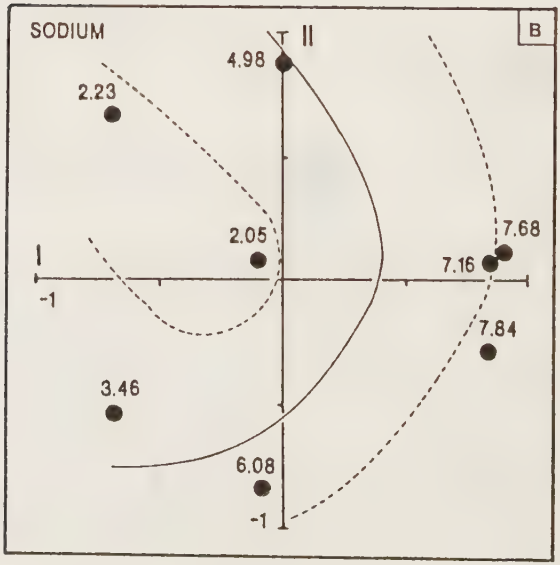
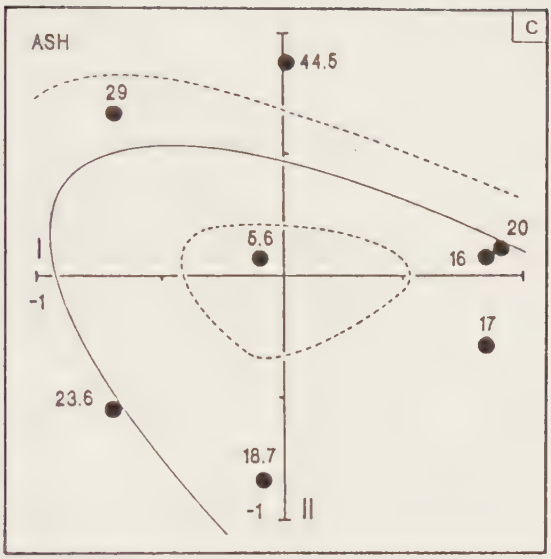
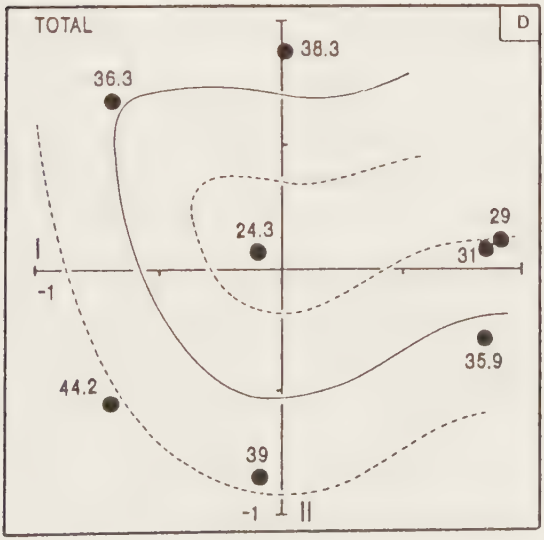


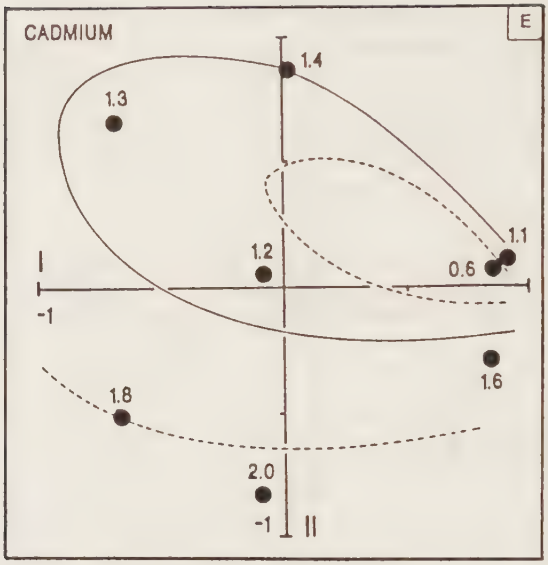
Figure 31: Principal components analysis based on mean tissue element and heavy metal concentrations in *S.californicus*. Magnitude of variables on component III is represented by circle diameter; closed circles are negative values and open circles positive values. A. tissue potassium; B. tissue sodium; C. total ash; D. total element; and E. tissue cadmium mean concentrations of the bulrushes superimposed on components I and II.


A
POTASSIUM
21.2
15.6
13.5
14.9
16.6
I
-1
19.7
31.3
25.3
-1
II


B
SODIUM
II
4.98
2.23
2.05
7.68
7.16
I
-1
7.84
3.46
6.08
-1


ASH
C
44.5
29
20
5.6
16
I
-1
17
23.6
18.7
-1
II


TOTAL
D
38.3
36.3
29
24.3
31
I
-1
35.9
44.2
39
-1
II



lowest potassium levels and from Tarumã Lake the highest ones. Sodium concentrations plotted in a three factor space (Fig. 31.B) showed a high sodium content in the bulrushes from those lakes which were grouped on the positive pole in the first axis of the PCA. Low levels (Na<X-1SD) were obtained in *S.californicus* from both Caieira and Barros lakes.

Tissue phosphorus and tissue zinc concentrations, both grouped in the Component III, did not show any consistent pattern. Plant ash (Fig. 31.C), however, occurred alone in the Component IV of the PCA that accounted for 11.0% of the total variance, and showed an increasing pattern between the lakes, but no north-south gradient was denoted.

It seemed likely that total nutrient concentration is highly dependent on tissue potassium levels. A weak north-south gradient in the coastal lakes was also observed for tissue total nutrient concentrations (Fig. 31.D) as already mentioned for potassium. Caieira and Palmital lakes showed the lowest levels whereas Taruma Lake presented the highest ones.

Not only site and geographical variation promote large differences in tissue element, but also stand structure and seasonal changes. The mean coefficient of variation in tissue element of *S.californicus* varied from season to season in Saco de Tapes (Table 27). The greatest variation in summer occurred undoubtedly in tissue phosphorus concentrations. Nitrogen, calcium and magnesium had a low mean coefficient of variation compared with the other elements, suggesting that in Saco de Tapes these elements were much more carefully regulated in summer.

Plant height presented very little variation in summer which reflects a high stand homogeneity. Nevertheless, an increasing height heterogeneity was observed from autumn to spring, when the stand is structured by both old tall and new short stems.

In winter, tissue nutrients showed a low mean coefficient of variation suggesting that they were more regulated in the system (Table 27). The only great variation was observed in tissue sodium, which is not an essential element, but varied in the plant according to the incoming salt water from the sea, and that reached the system during winter months through the Patos Lagoon.

In autumn and spring, nitrogen was the most carefully regulated nutrient in Saco de Tapes system regarding plant retention.

The contrast and variability in tissue elements during the winter and summer surveys are shown in the relative deviation of element concentration presented in Fig. 32.

Table 27: Mean element concentrations in *S.californicus* of Saco de Tapes. Concentrations are averaged for samples taken across the seasons (µg/g dry weight).

	summer (CV) n=495	autumn (CV) n=318	winter (CV) n=375	spring (CV) n=483
P	5010 (94.03)	2539 (19.44)	2268 (29.16)	1827 (25.48)
N	8072 (15.45)	7173 (2.82)	8127 (24.80)	6608 (11.12)
Ca	1834 (17.66)	1352 (7.07)	1544 (18.81)	1777 (30.15)
Mg	1063 (10.68)	769 (15.28)	1207 (21.40)	1468 (19.49)
Na	3478 (24.50)	3475 (4.33)	3558 (85.30)	3108 (40.77)
K	12431 (49.62)	15932 (33.53)	18594 (23.16)	22708 (25.94)
Zn	27.03 (49.30)	26.57 (24.76)	20.91 (22.48)	32.01 (67.45)
Cu	1.48 (18.66)	1.30 (29.92)	3.03 (38.35)	1.81 (23.44)
Cd	0.86 (22.13)	1.34 (20.58)	0.75 (65.45)	1.10 (31.50)
Pb	0.31 (51.91)	0	only east	only west
ash	27.56 (12.41)	24.42 (8.11)	26.70 (53.36)	28.19 (10.70)
total	31917 (15.38)	31269 (19.49)	35321 (21.95)	37530 (16.47)
biomass	297 (23.29)	231 (30.35)	279 (49.68)	191 (35.01)
height	2.25 (5.54)	2.15 (11.01)	1.89 (18.83)	2.00 (25.53)

In the south margin sodium influence in winter is not so notorious as it is in the north edge. Nevertheless, bulrushes at the southern margin presented high cadmium content compared to other sites. Such tendency may be a result of the special location of this margin, which is influenced by water currents (HERZ, 1974) from both north and south portions of Patos Lagoon. Studies carried out in the Patos Lagoon estuary revealed high heavy metal contamination levels in the sediments of the area (BAISCH et al., 1988). Especially cadmium concentrations reached high values in the estuary. It seemed likely that in winter heavy metals may enter the Saco de Tapes system by

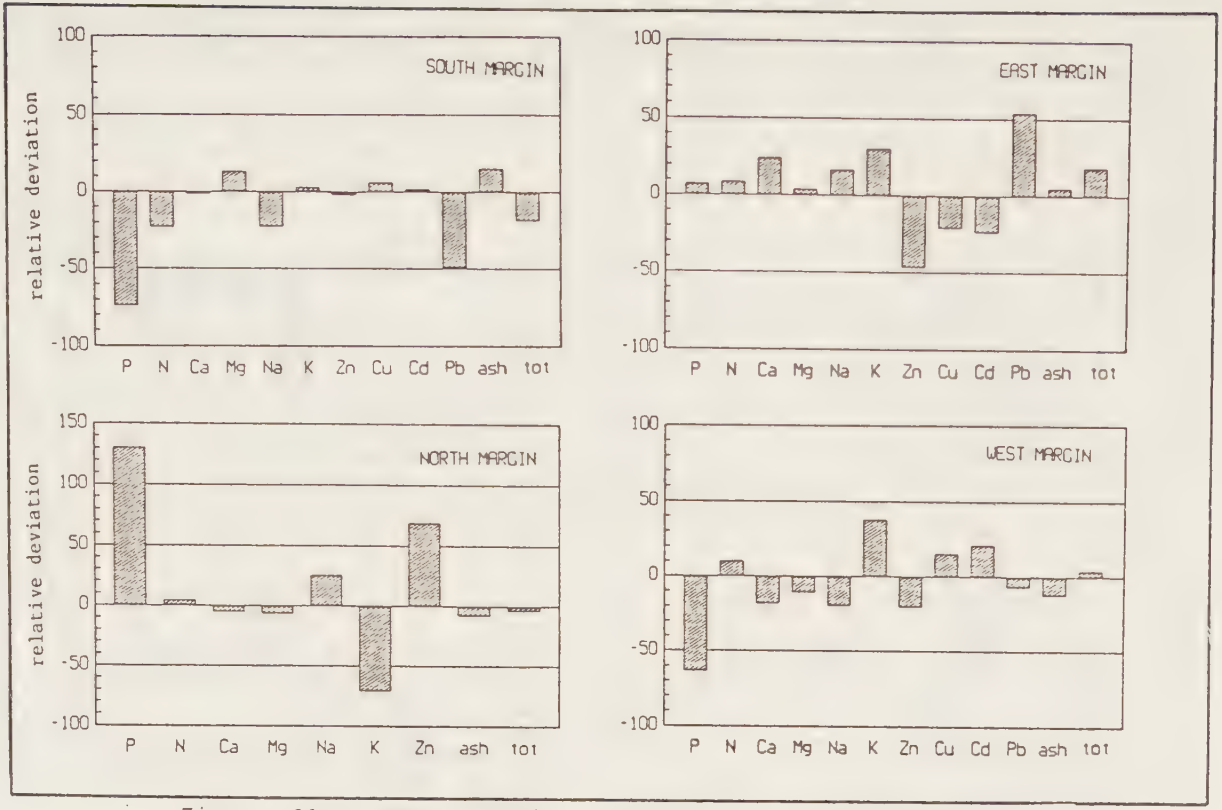


Figure 32a: Mean relative deviation of the element concentration of bulrushes from different margins in Saco de Tapes in summer.

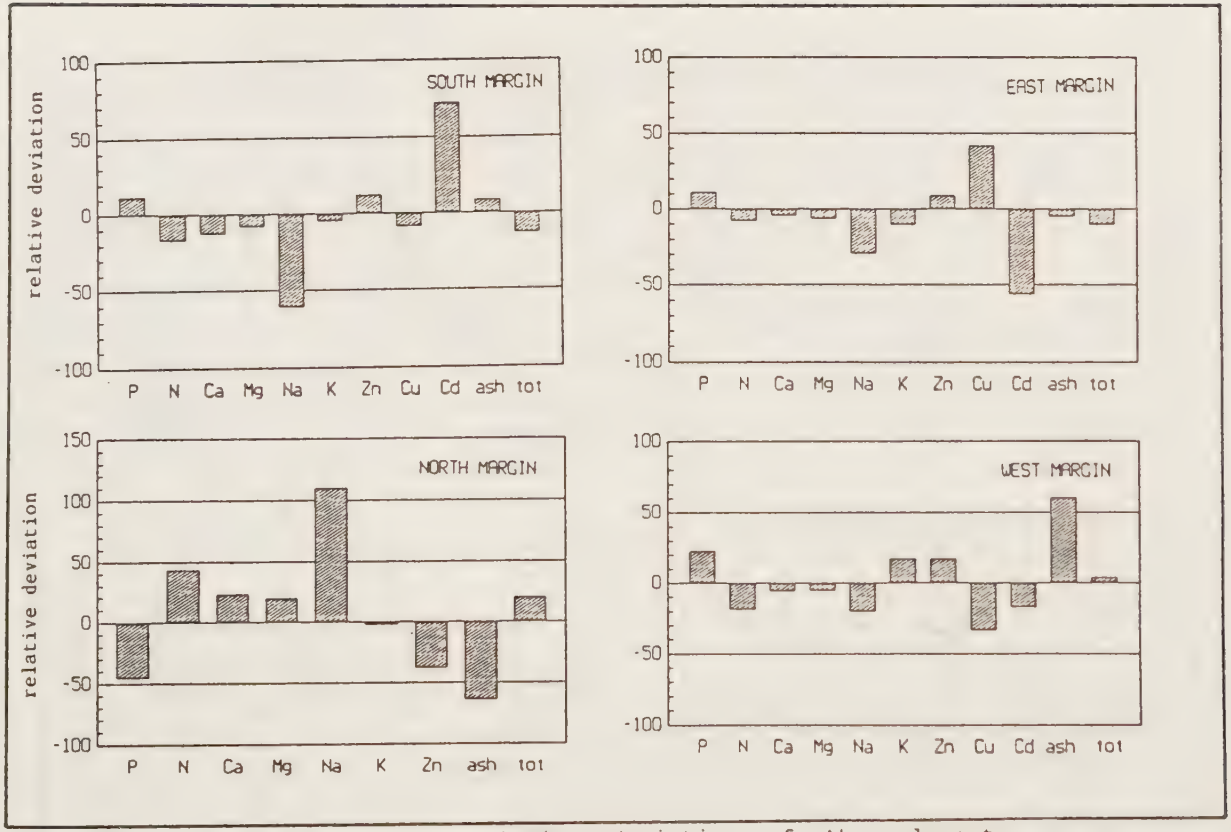


Figure 32b: Mean relative deviation of the element concentration of bulrushes from different margins in Saco de Tapes in winter.

incoming water from Patos Lagoon, and overcome local influences. In this place where fresh- and salt-water intermix, metal may accumulate due to flocculation processes (SALOMONS & FÖRSTNER, 1984). The high tissue cadmium accumulation in bulrushes from the south margin, however, is followed by a low tissue sodium. The location of the margin also contributes to such mechanisms. A significant correlation was obtained between tissue sodium and cadmium concentration in the sediments of the littoral zone of Saco de Tapes (Table 28). The local

Table 28: Simple correlation coefficients relating mean sediment elements to mean tissue element concentrations in *S.californicus* from Saco de Tapes.

Tissue element	soil element concentration									
	P	N	Ca	Mg	Na	K	Zn	Cu	Cd	Pb
P	-.36	-.41	-.21	-.32	-.32	-.36	-.34	-.43	.43	-.42
N	-.35	-.34	-.33	-.48	-.47	-.47	-.62*	-.36	.15	-.61*
Ca	.29	.32	.22	.34	.37	.28	.20	.34	.32	-.20
Mg	.31	.14	-.13	.22	.26	.20	.29	.19	.19	-.05
Na	-.36	-.32	-.04	-.12	-.11	-.14	-.11	-.25	.60*	-.58
K	-.04	-.32	-.35	-.43	-.40	-.53	-.19	-.48	-.50	-.31
Zn	.30	.40	.35	.28	.31	.18	.50	.33	-.06	.11
Cu	.01	-.21	-.31	-.17	-.29	-.12	-.23	.15	-.27	.08
Cd	-.20	.02	.39	-.04	.06	-.05	.18	-.12	-.39	-.03
Pb	-.32	-.18	-.30	-.19	-.28	-.09	-.42	.16	-.18	-.33
ash	.37	.15	-.02	.29	.22	.11	.27	.13	.76**	.05
total	-.21	-.42	-.36	-.46	-.43	-.55	-.31	-.53	.64*	-.56
biomass	-.08	-.20	-.15	.35	.24	.33	.23	-.03	.63*	.32
height	.20	.18	.52	.38	.44	.29	.49	.12	.17	.16

$P<0.05$(*); $P<0.01$(**).

dynamics of the north edge, mainly a consequence of water level and wave action, promotes an unidirectional element accumulation. Total element concentration was relatively high at this margin, and tissue sodium may be a result of such trends in winter.

In summer, tissue phosphorus played an important role in the macrophytes of Saco de Tapes. North and south margins contrasted greatly regarding this element (Fig. 32). In winter lead was detected only in bulrushes from the eastern shore, and in summer this element appeared in *S.californicus* from other margins and was more expressive than cadmium.

Correlation coefficients between plant elements were significant in many cases (Table 29). Among individual elements, as expected, tissue potassium presented the

Table 29: Simple correlation coefficients based on intraspecific variation in the aboveground tissue elements in *S.californicus* from Saco de Tapes.

	P	N	Ca	Mg	Na	K	Zn	Cu	Cd	Pb	ash
P	1.0										
N	.45	1.0									
Ca	.59*	.34	1.0								
Mg	-.16	-.42	.24	1.0							
Na	.68*	.18	.38	-.22	1.0						
K	.05	-.24	-.45	.32	.12	1.0					
Zn	-.34	-.61*	-.51	-.10	.12	.22	1.0				
Cu	-.14	-.04	-.17	.42	-.22	.20	-.15	1.0			
Cd	-.31	-.14	-.55*	-.50	-.48	-.07	.17	-.49	1.0		
Pb	.23	.43	.38	.19	.23	-.23	-.35	.69*	-.74**	1.0	
ash	.06	-.32	.13	.55*	.06	.52	-.11	.21	-.46	-.11	1.0
tot	.60*	.20	.03	.15	.54	.80**	-.08	.08	-.33	.05	.43

P<0.05 (*); P<0.01 (**); P<0.001(***).

highest proportion of the total variance accounted for by the Component I of the principal components analysis. The high coefficient of variation presented by tissue phosphorus in summer and by tissue sodium in winter, included the former on the negative pole of the Component I, and the latter in the third axis of the PCA (Fig. 33).

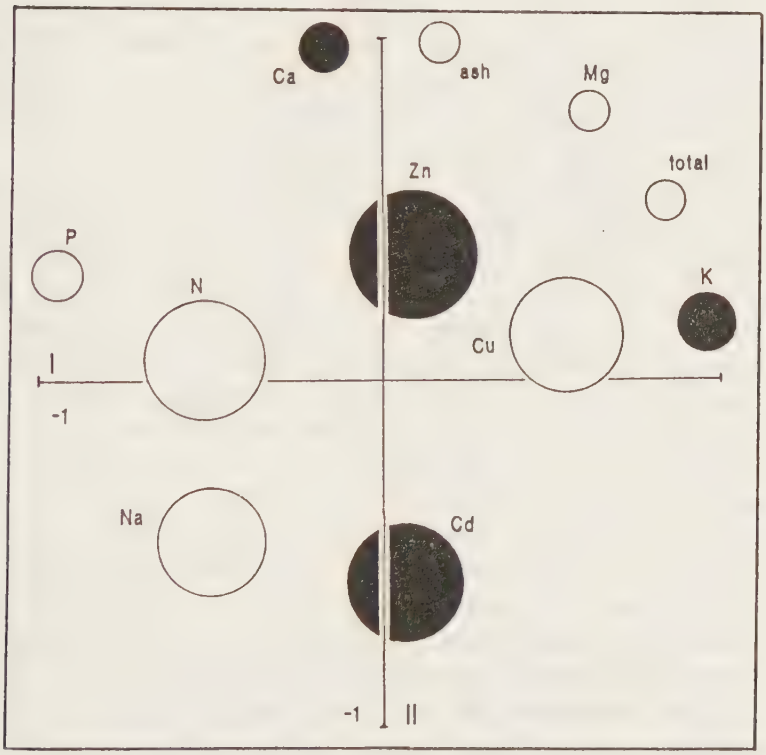


Figure 33: Principal components analysis of ash, total, and individual elements in aboveground tissue of *S.californicus* from Saco de Tapes, over a year period. Components I and II accounted for 46.4 and 31.1% of the total variance; component III that accounted for 22.4% of total variation is represented by circle diameter with open and closed circles expressing positive and negative values, respectively.

The principal components analysis indicated that tissue potassium and total tissue elements presented a tendency to cluster on the positive pole of the first axis (Fig. 33), that accounted for 46.4% of the total variance during all the year. Tissue calcium, magnesium and total ash grouped on the positive pole of the second component, that accounted for 31.1% of the total annual variation. Tissue nitrogen grouped on the third component together with sodium and the heavy metals.

Between-season comparisons based on principal components analysis showed that tissue elements differed widely in their relative levels. Whereas tissue phosphorus decreased from summer to spring, tissue potassium showed an antagonistic trend (Fig. 34).

Sediments of the littoral zone of Saco de Tapes always showed slightly higher lead levels compared to cadmium contents. Nevertheless, an opposite trend was observed in the macrophytes, and tissue cadmium was higher than lead concentrations. Lead concentrations in roots of terrestrial plants are directly correlated to lead contents in soils (HOCK & ELSTNER, 1988). The nutrient concentration and heavy metal contents in the rhizomes of *S.californicus* were highly related to sediment element contents (Table 30). Such type of relationships have already been mentioned by HUTCHINSON (1975) for copper contents in rhizomes of some aquatic macrophytes. Sodium concentration in the rhizomes showed a positive relation to other elements in the sediment, whereas magnesium presented opposite trend.

The concentrations of individual tissue elements, however, were not directly correlated to sediment concentrations (Table 28). Furthermore, the absence of biomass-sediment nutrients relationships implies that in the Saco de Tapes system *S.californicus* is not nutrient-limited.

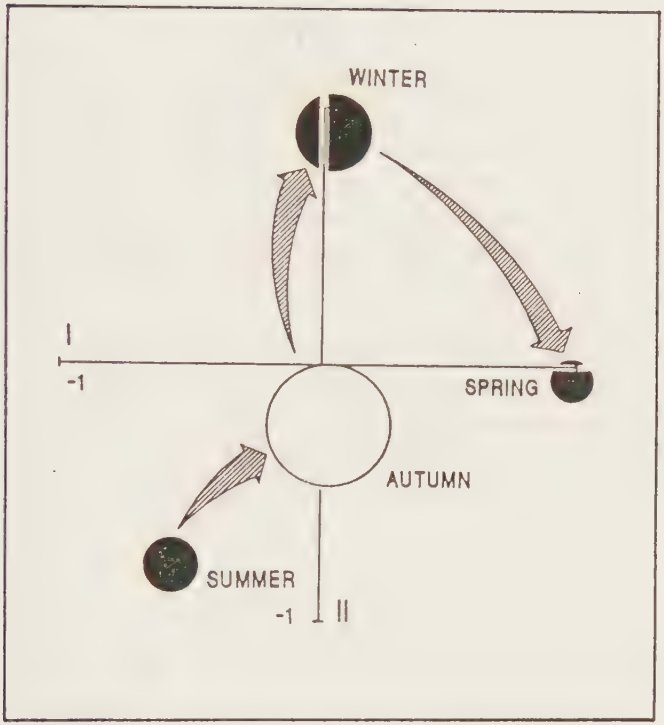


Figure 34: Routes of potassium enhancement as shown in the Principal Components Analysis based on seasonal tissue element concentrations in *S.californicus* from Saco de Tapes. Component I and II accounted for 48.8 and 37.15% of total variation. Component III (14.1% of the total variance) is represented by circle diameters with positive and negative values expressed by open and closed circles, respectively.

Table 30: Simple correlation coefficients relating mean sediment elements to mean element concentrations in the rhizomes of *S.californicus* from Saco de Tapes.

rhizome	sediment								
	P	N	Ca	Mg	Na	K	Zn	Cu	Cd
P	-.76***	-.19	.61**	-.22	-.34	-.29	-.35	-.06	-.003
N	-.57**	-.14	.44*	-.16	-.25	-.21	-.27	-.05	-.009
Ca	-.20	-.42	-.55**	-.41	-.34	-.37	-.45*	-.45*	-.54*
Mg	-.64**	-.77***	-.42	-.77***	-.74***	-.76***	-.81***	-.76***	-.79***
Na	.32	.89***	.73***	.87***	.80***	.83***	.77***	.94***	.92***
K	-.27	.45*	.90***	.42	.30	.35	.29	.59**	.62**
Zn	.53*	.29	.12	.30	.29	.30	.45*	.25	.34
Cu	-.44*	.32	.72***	.29	.19	.23	.09	.44*	.42
Cd	-.18	-.61**	-.66**	-.60**	-.52*	-.56**	-.55*	-.66**	-.70***

P<0.05(*), P<0.01(**); P<0.001(***).

STEM HEIGHT AND DENSITY

Important morphological differences were observed in stands of *S.californicus* in Saco de Tapes, already mentioned by ARAUJO DE OLIVEIRA & NHUCH (1986) and NHUCH VERLANGIERI (1989). The height and density of the bulrushes varied between the margins, and between the seasons, according to environmental factors, and location and exposition of the littoral zone.

Mean stem height showed a significant difference between summer and winter ($F=12.993$; $d.f.=16,160$; $P<0.001$). Among the edges, in summer, northeast, north

and "esporão" differed statistically from the others ($F=12.819$; $d.f.=8,91$; $P<0.001$), and in the winter the south and south-bay edges were the most different ($F=10.126$; $d.f.=7,69$; $P<0.001$).

Between the seasons, the southeast ($t=3.096$; $d.f.=11$; $P<0.05$), east ($t=5.113$; $d.f.=19$; $P<0.001$), north ($t=4.702$; $d.f.=16$; $P<0.001$) and southwest margins ($t=4.44$; $d.f.=21$; $P<0.001$) showed different stem heights. If each margin is compared according to the distance of the sampled belt from the shore, in summer, no significant difference was observed ($P>0.05$) between the three zones. In winter stem height differed ($F=2.467$; $d.f.=11,58$; $P<0.05$) within the same margin, probably due to the rising water level. Although such factor can promote disturbance on the features of the stands, some studies performed with *S.californicus* have demonstrated that stems which are constantly submersed can show an increase in height and density (TUR & ROSSI, 1976).

The sample sets which were influenced directly by environmental factors, as observed throughout the year in the "esporão" and southern edges, showed the more homogeneous stands (Fig. 35). The former presented the lowest stem height compared to all sampled stands. Important to note is that stems in the "esporão" during winter were completely submersed, but in summer rhizomes were very superficial and exposed to dryness at the shoreline. The importance of a hard rhizome, as mentioned by HUTCHINSON (1975), in this case, constitutes a fundamental factor that ensures the maintenance of the stands throughout the year.

The analysis of variance performed between the margins showed a significant difference ($F=9.06$; $d.f.=8,168$; $P<0.001$) which separates the southern portion of Saco de Tapes from other edges, but not from the southeast and west.

Stem density increased significantly from summer to winter specially in the east ($t=4.397$; $d.f.=29$; $P<0.001$), northeast ($t=3.186$; $d.f.=28$; $P<0.01$), west ($t=2.615$; $d.f.=20$; $P<0.05$) and southwest margins ($t=2.348$; $d.f.=21$; $P<0.05$). Stem density during winter differentiated only the southwest from the north margin ($F=3.728$; $d.f.=7,69$; $P<0.01$), whereas other margins remained relatively homogeneous. The rise in the water level during winter, appears to contribute to such features, influencing not only stem height, but also its density. In summer, both edges located in the south of the system - "esporão" and southwest - showed structural similarities, whereas other sites were statistically different ($F=14.17$; $d.f.=8,108$; $P<0.001$). The absence of differences between sampled squares regarding stem density in the same margin during winter, confirms the homogeneity of separate stands in this season.

Greater individual abundance was observed in the southwest and in "esporão" edges (Fig. 36). At least 22% stems in the former were in the class of 81-90 individuals/m^2, whereas in the latter 67% were included in the class of 71 to 90 individuals/m^2. "Esporão" showed, exception of the lowest stand, the higher stem density.

Tha analysis of variance performed throughout the year differentiated three sites: south-bay, southwest and "esporão" ($F=11.53$; $d.f.=8,185$; $P<0.001$).

Such observations, if compared to the "Scirpus californicus Density Index" (IDSC) developed by NHUCH VERLANGIERI (1989) on stands in Saco de Tapes, show several differences. The index does not intend to represent the real number of stems per square meter, but a visual density cover by the macrophyte stands. It is presumable that, if data obtained by stem numbers in the quadrat method show a decreasing density while the index increases, it demonstrates an enhancement in diameter of

stems. On the other hand, if the contrary occurs, one can not relate it directly to thinning, but to the appearance of new shoots not detected by the Index. Such

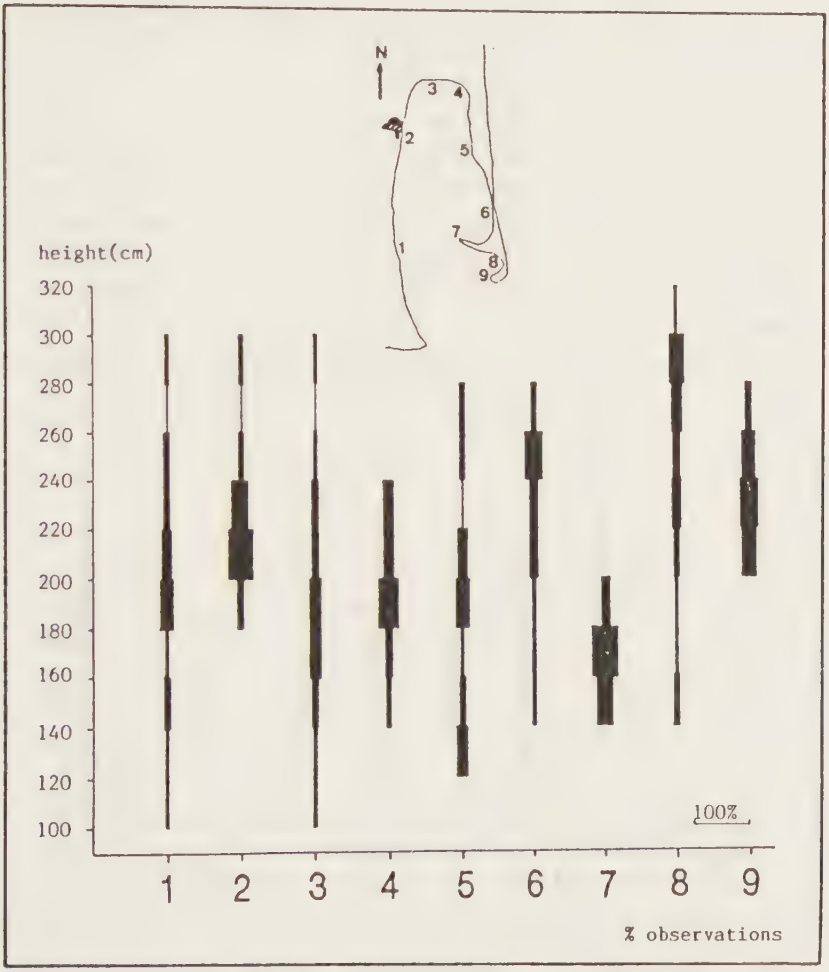


Figure 35: Vertical distribution of percent observations of stem height (cm) in *S.californicus* in nine margins of Saco de Tapes.

observations were clearly demonstrated in other studies (ARAUJO DE OLIVEIRA & NHUCH, 1986).

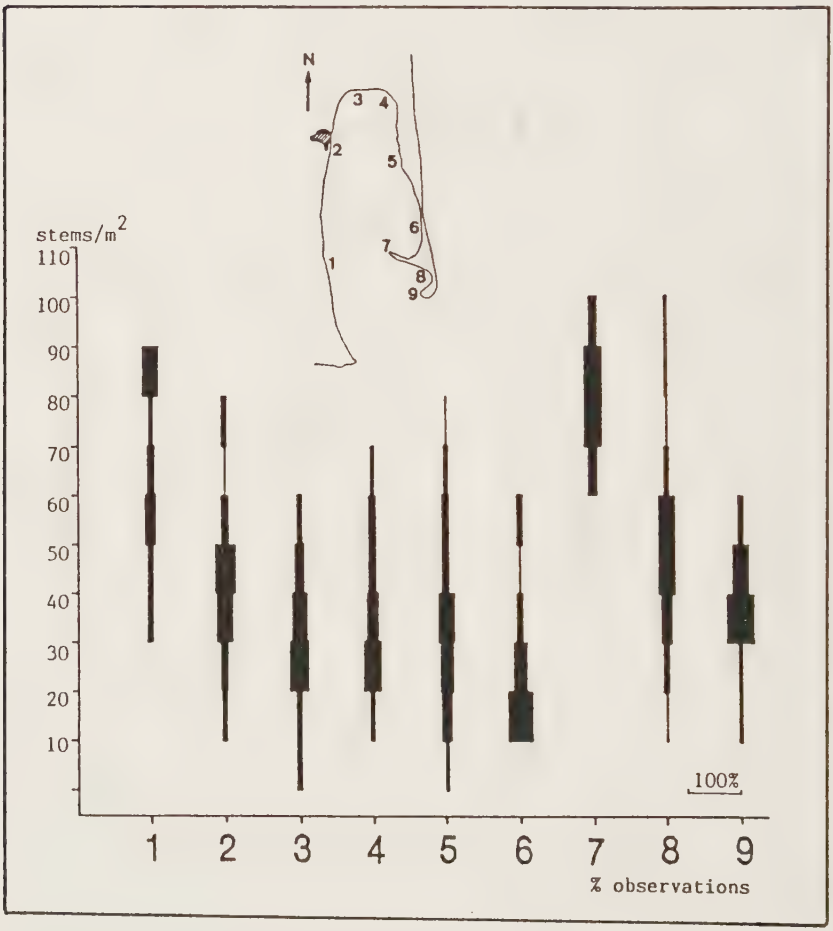


Figure 36: Vertical distribution of percent observations of stem density (no./sq.m) in *S.californicus* in nine margins of Saco de Tapes.

DENSITY RELATIONSHIPS

Some authors have demonstrated that there is a high inverse relationship between mean shoot weight and density in aquatic macrophytes (GORHAM, 1979; DUARTE & KALFF, 1987) but differences among stands were dependent on light incidence. Nevertheless, in emergent macrophytes, stem density is found to be restricted by environmental controls (HUTCHINGS, 1979), and number of shoots and biomass at maturity remain fairly constant in undisturbed places. Data obtained in summer and winter, in stands of *S.californicus* in Saco de Tapes, have shown that in such a system, the weight-density relationships were highly season dependent. A relation between both parameters, described by the equation:

log weight=1.71-0.54log density (Eq.1) (Fig. 37)

was noted only in the summer, when the stands were more homogeneous. Probably the disturbance promoted by the mechanical effects of wave action was the most important factor of heterogeneity in winter. The very short and numerous stems showed by bulrushes' stands in the "esporão" of Saco de Tapes may be a consequence of salinity influence, as well as a result of the very superficial rhizome layer. Factors such as tidal inundation, salinity, sediment redox potential, ion toxicity, and nutrient deficiencies are known to play an important role in determining the height of emergent macrophytes (MENDELSSOHN, 1979). Thus, the height forms are results of environmental differences, rather than genetically different ecotypes in the same species (MENDELSSOHN, 1979). Deviations in the weight-density relationship of stands of submerged macrophytes were explained also by the variations in the biomass

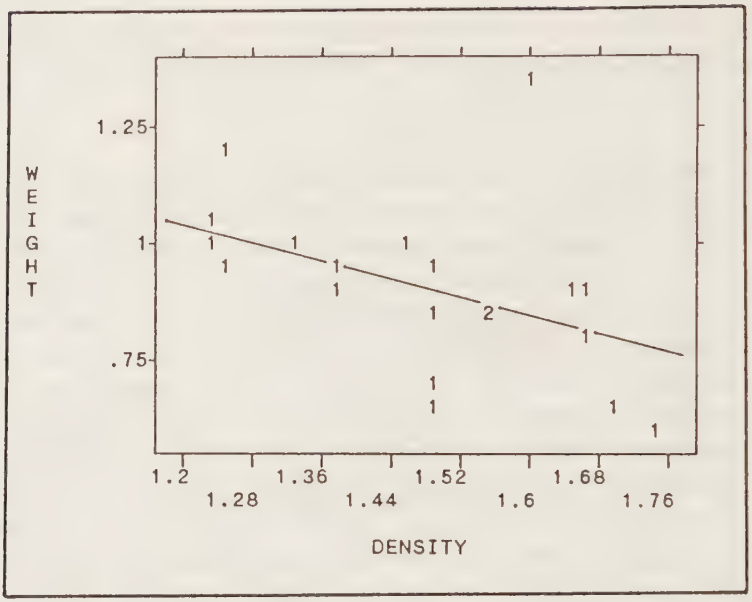


Figure 37: Relationship between plant weight (g dry wt) and plant density (no.stems/m^2) in summer. The line represents the regression equation (Eq.1).

associated with the species growth (DUARTE & KALFF, 1987).

The lack of thinning is known to result in the development of monospecific stands of clonal perennials. Such aspects had already been mentioned by HUTCHINGS (1979), regarding some emergent macrophytes. Besides increase in number and a decrease in height per square meter, the bulrushes harvested in the "esporão" showed also narrow stems. HASLAM (1971) has observed that primary control over height is belowground, and unfavourable environmental conditions lead to narrow shoots. Also salt water flooding through the "esporão" edge, among other physical factors, could explain the lower stem height in this place and the reduction of

shoot diameter. Rather than space, light seems to be the limiting resource to individual plant size at a given density. Such observation is valid specially in emergent macrophytes whose leaves are held essentially in a horizontal position. *S.californicus* is vertical element and probably light, in this case, plays a second role to the plant density. The importance of the horizontal and vertical structures of emergent macrophytes stands has been demonstrated specially in temperate regions (ONDOK, 1970, 1971; DYKYJOVÁ, 1973a; DYKYJOVÁ & PRIBIL, 1975).

The heterogeneity of the stands during winter was probably a result of the high water level which reached the system during that period, associated to flowering. Furthermore, only in winter a high relationship was obtained between aboveground biomass and stands density ($P<0.01$) (Fig. 38), and aboveground biomass and stem height ($P<0.001$) (Fig. 39), that could be described by the equation:

$$\log \text{biomass} = 1.25 + 0.67 \log \text{density} \quad \text{(Eq.2)}$$

$$= 1.89 + 1.60 \log \text{height} \quad \text{(Eq.3)}$$

Some correlations were also found between biomass and stand height for *Spartina alterniflora* in marshes (NIXON & OVIATT, 1973), as well as for *Bolboschoenus maritimus* in a wetland area (KRISCH, 1986). HARDWICK & ANDREWS (1983) have already described the relationship between biomass in pure stand, plant density, and time, based on the assumption that such relationship can be approximated by a rectangular hyperbola and that crops of the same biomass grow at the same rate.

In *S.californicus*, stem height and stand density showed considerable variation and, as a matter of fact, no relationship between such structural features was found.

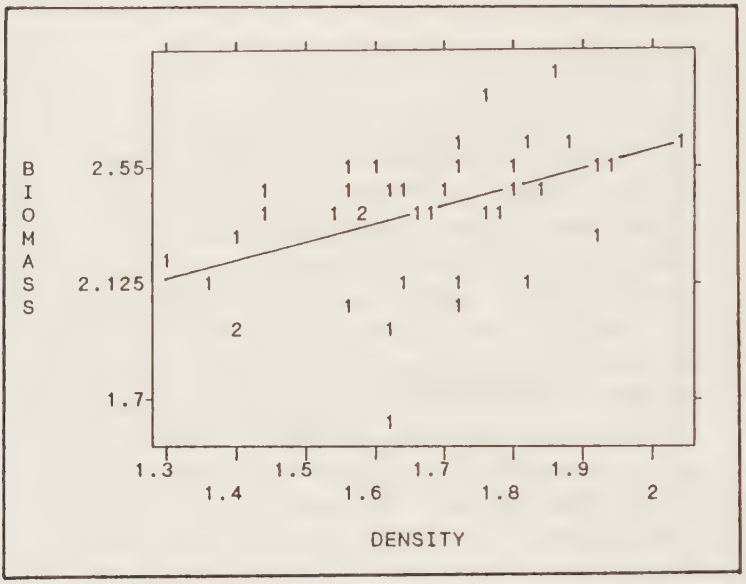


Figure 38: Relationship between aboveground biomass (g dry wt/m^2) and plant density (no.stems/m^2) in winter. The line represents the regression equation (Eq.2).

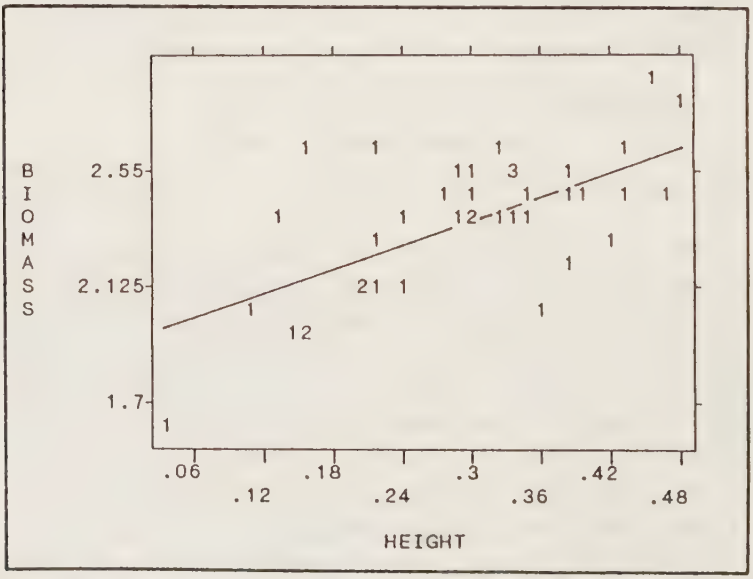


Figure 39: Relationship between aboveground biomass (g dry wt/m^2) and plant height in winter. The line represents the regression equation (Eq.3).

In oligotrophic lakes, *Phragmites communis* density is known to be limited by nutrient deficiency (HASLAM, 1971), and an increase in nutrients is followed by an increase in density (BJÖRK, 1967; SPENCE, 1982).

BIOMASS PATTERNS

Many environmental gradients are known to be responsible for differences in growth and biomass in aquatic plants (DeLAUNE et al., 1979; WILSON & KEDDY, 1986a, b). Also macrophytes growing at the shoreline can vary greatly their biomass at a gradient according to the organic contents of the substratum (SCHIEMER & PROSSER, 1976; WILSON & KEDDY, 1985; BARKO & SMART, 1986). Variations in the biomass of submerged and emergent plants and their distribution are often related to sediment features (MISRA, 1938; BARKO & SMART, 1978, 1980, 1981, 1983, 1986; CARIGNAN & KALFF, 1979; DeLAUNE et al., 1979; BARKO, 1982, 1983; SPENCE, 1982; HUEBERT & GORHAM, 1983; SMART & BARKO, 1985; ANDERSON & KALFF, 1986) and salinity can play an important role on it (MORRIS, 1980; HAUENSTEIN & RAMIREZ, 1986; HOWES et al., 1986). Emergents as *S.alterniflora* in marine marshes show an antagonistic relationship between growth and interstitial salinity of the underlying sediments (NESTLER, 1977), and a close relation to sediment oxidation (HOWES et al., 1986). Also recently, KRASKA et al. (1986) found out that differences in patterns of *T.latifolia* reflect genetic heterogeneity, but not differences caused by dissimilar habitat conditions.

S.californicus in Saco de Tapes system showed a clear biomass variation throughout the year. In summer, bulrushes presented the highest biomass but the lowest

coefficient of variation (Table 27) reflects high stability between different stands in Saco de Tapes. In spring the mean biomass was low and the coefficient of variation was higher than in summer. However, bulrushes in winter appeared with the highest variation mainly due to both growth of new stems and senescence of the older ones in the same period.

Emergent macrophytes in temperate regions show well defined growth periods, while in the tropics (WETZEL, 1975) and subtropics the aboveground biomass remains apparently constant (WESTLAKE, 1982), and production and losses are near equilibrium throughout the year (WESTLAKE, 1963). Moreover, it seems likely that in tropical waters the aboveground biomass of aquatic macrophytes is higher than the belowground, probably due to the absence of a complete "die-back" (PAYNE, 1986). On the other hand, belowground biomass of salt marshes plants in subtropical (DE LA CRUZ & HACKNEY, 1977; HACKNEY & DE LA CRUZ, 1986) and temperate regions (KENTULA & McINTIRE, 1986) seems to be greater than aboveground parts.

The combination of species at any site presents a potential maximum biomass that depends on the irradiance and self-shading (WESTLAKE, 1982). In tropical and subtropical regions, the whole plant production can exceed the maximum values found for the same species in temperate zones (ROBERTS & GANF, 1986). Higher temperatures and daily irradiances in winter, as well as longer daylenghts, contribute to a continuous growing season in emergent macrophytes in the tropics and subtropics.

Great attention has been paid to the aboveground biomass production by aquatic macrophytes in marshes and in the littoral zone of lakes (NIXON & OVIATT, 1973; ONDOK, 1973; ONDOK & DYKYJOVÁ, 1973; DYKYJOVÁ & PRIBIL, 1975; SCHIEMER & PROSSER, 1976; MOOK & VAN DER TOORN,

1982; GRANÉLI, 1983, 1984, IHSE & GRANÉLI, 1985; KRISCH, 1985, 1986), as well as in estuarine systems (BROOME et al., 1975a, b; GALLANGHER, 1975; PATRICK & DeLAUNE, 1976; DeLAUNE et al., 1979 BURESH et al., 1980). The estimation of the annual productivity of emergent macrophytes can be made by evaluations of the biomass changes. Nevertheless, stands with a very stable or irregular changing biomass may be problematic (RICH et al., 1971; WESTLAKE, 1975).

Depending on the edge location, *S.californicus* harvested in Saco de Tapes showed great differences in the aboveground biomass (Fig. 40). Whereas in the southern edge, aboveground biomass decreased from summer to winter, in the eastern margin it remained relatively constant. A contrasting situation was observed in bulrushes in the northern and western edges. In the former, aboveground biomass in winter was extremely low, and in the latter an increase was notorious. The northern edge, in winter, is highly impacted by wind and wave action, as well as by an increase in water level. Since the slope in this margin is more attenuated, the flooding water reaches a greater part of the littoral zone and the shore. All these factors contribute to the reduction of the bulrushes' biomass in winter. Reduction in extent of macrophytes during winter in relation to the increase in water level (SCHIEMER & PROSSER, 1976, NHUCH VERLANGIERI, 1989), and the influence of littoral slope on macrophytes' biomass due to physical alteration of the sediments (DUARTE & KALFF, 1986) have already been reported. On the other hand, in the western margin, winter appeared to be the best season for bulrushes' increasing biomass, although a great part of the stands remained under water due to the rising water level. Since this margin is directly influenced by human recreational activities during summer, bulrushes' stands are re-established only in winter.

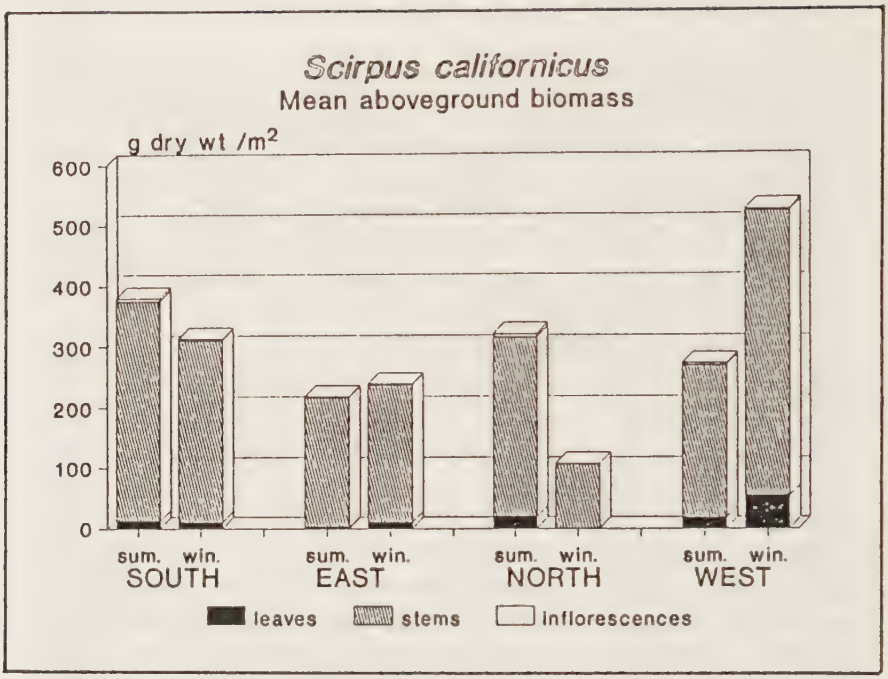


Figure 40: Comparison of the mean aboveground biomass of *S.californicus* in selected margins in Saco de Tapes.

Although *S.californicus* showed a continuous growth throughout the year, a slight maximum biomass was observed in summer (about 350 g dry weight/m^2) (Fig. 41). An increase in the mean aboveground biomass was also detected in the winter when new shoots began to appear in the stands. These observations are consistent with data mentioned by MITCHELL & ROGERS (1985) for *T.domingensis* stands in a tropical lake. Leaves varied between 2.1 and 4.5% of the total biomass, and although containing high concentrations of mineral elements, inflorescences' contribution to the total biomass was very low.

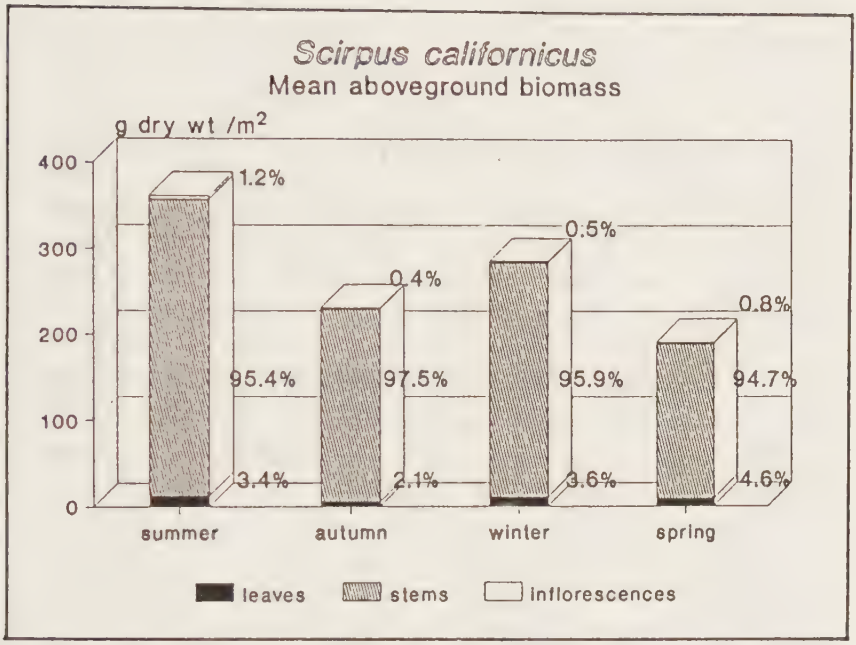


Figure 41: Mean aboveground biomass and relative proportion of stems, leaves and inflorescences in different seasons.

Maxima mean aboveground biomass of bulrushes in nine lakes of the Coastal Plain reached about 137 g dry weight/m^2 in summer. In winter biomass was slightly higher (199 g dry weight/m^2). Although winter and summer aboveground biomass relations in bulrushes of the coastal lakes presented inverse trends compared to those of Saco de Tapes, in the latter biomass was by far higher than in the former ones.

In Saco de Tapes, stems and leaves contributed to a biomass estimated at about 3.6 ton dry matter/ha in

summer, and 2.8 ton dry matter/ha in winter. Autumn and spring presented lower biomass (2.3 and 1.9 ton dry matter/ha, respectively). These values are not specially high if compared to the biomass production of reeds (DYKYJOVÁ & HUSAK, 1973; GRANÉLI, 1983, 1984) and some other macrophytes (BIRCH & COOLEY, 1982; ONDOK, 1973; ONDOK & DYKYJOVÁ, 1973; KRISCH, 1985; ROBERTS & GANF, 1986). However, based on the fact that the biomass production of bulrushes in subtropical regions occurs throughout the year, the annual production may surpass those values obtained for the reeds in temperate zones.

Differences in the nutrient contents of the aboveground biomass of *S.californicus* in an annual cycle showed some peculiarities due to the undefined growth period of this cyperacea. Two peaks of mineral uptake were clearly shown by the bulrushes in the summer and in the winter seasons (Table 31), contrasting to temperate regions where summer sustains the maximum biomass and mineral elements. A large fraction of phosphorus present in the aboveground biomass during the summer was lost to the system or returned to the rhizomes in autumn. Recycling phosphorus to the rhizomes, at similar proportions, was already observed in reeds (GRANÉLI, 1983). In the bulrushes, nitrogen and potassium decreased to 45 and 48%, respectively, from summer to autumn.

From autumn to winter, an increase in phosphorus, nitrogen and potassium, assumed to be derived from rhizome storage, was observed in the aboveground biomass (Table 31). Such fact may be related to the appearance of new shoots during winter months. Although with lower proportions, a second decrease (due to translocation or leaching) in nutrients was detected from winter to spring. Nevertheless, in the subsequent season, large proportion of phosphorus was required for the growth and maintenance of the stands till the end of the summer. All year round, loss and uptake of nitrogen were the least

Scirpus californicus

Nutrient cycling

AUTUMN	kg/ha	% summer value
N	17.1	- 45
P	4.7	- 74
K	36.0	- 48
standing crop:	2.3	ton/ha

WINTER	kg/ha	% autumn value
N	28.7	+ 40
P	6.5	+ 28
K	62.3	+ 42
standing crop:	2.8	ton/ha

SPRING	kg/ha	% winter value
N	13.7	- 52
P	3.5	- 46
K	52.8	- 15
standing crop:	1.9	ton/ha

SUMMER	kg/ha	% spring value
N	31.4	+ 56
P	18.3	+ 81
K	68.7	+ 23
standing crop:	3.6	ton/ha

Table 31: Seasonal standing crop, phosphorus, nitrogen and potassium annual variations based on element content in the aboveground biomass of *S.californicus* harvested in in Saco de Tapes.

variable. It appears that the cycling of phosphorus is more efficient than the other two nutrients in the bulrush stands in Saco de Tapes.

FINAL REMARKS AND CONCLUSIONS

Subtropical emergent macrophytes present two annual peaks regarding aboveground biomass: summer and winter. Such observations contrast with data obtained for reeds and other emergents in the temperate regions.

Mechanical effects of wave action and water level are likely to be responsible for the variation in density of *S.californicus* and for the low number of other species within the same aquatic system. It seems likely that in open margins, monospecific stands of bulrushes dominate, and this is at least partly due to the fact that other plants are more affected by wind and waves actions. In the more sheltered margin, in the south of Saco de Tapes, other species occurred together with *S.californicus* but never penetrated more than a few meters of the open lake.

The spatial pattern of emergent macrophytes reflects the dynamics of the littoral involving thus many other factors associated with productivity and animal communities.

Emergent macrophytes in the coastal lakes are not nutrient limited as delineated by absence of sediment relationships. Although many variations were observed in bulrushes of different lakes in the Coastal Plain, the total nutrient in the tissues was relatively constant. Ash content, however, varied considerably.

Potassium was the most important and variable element in plant biomass and can be used in prediction models for the emergents of the coastal lakes. The main reason for low potassium content in sediments of the littoral zone is probably an active uptake by the emergent macrophytes, related to processes of growth and synthesis of the organic matter. Such remarks are consistent with data obtained from deeper sediment cores in which potassium

Salt-water effects in freshwater systems can be detected through tissue sodium concentrations, because bulrushes assimilate it even though not an essential nutrient.

The shoreline species was the most nutrient accumulator, whereas the bulrushes showed a high tendency to accumulate heavy metals. Lead appeared to be not easily taken up. Cadmium showed antagonistic relation to sodium, and its availability may be related to oxidized levels of the sediments. Heavy metals accumulate especially in leaves and inflorescences of emergent plants, and remain in these organs till the senescence. For this reason, bulrushes that have been grown in places where metal contamination is very high should never be used as animal food.

Enhancement of heavy metals in the upper strata of sediments, on the other hand, may result in biological availability and, consequently, in transport of heavy metals to aquatic food web.

Soluble nitrogen and phosphorus discharged into natural aquatic systems can stimulate vegetation growth and, consequently, accelerate lake eutrophication. Available forms of nutrient inducing eutrophication, and their release from suspended matter and sediments have to be taken into account when assessing nutrient control in aquatic systems.

Regarding the location of lakes, it is very difficult to distinguish natural and man-made eutrophication. Water hyacinths undoubtely constitute an important macrophyte to aquatic systems which are undergoing eutrophication by domestic and industrial wastes, or located close to agricultural areas. Nevertheless, its use as an index for the identification of the kind of contaminant present in the aquatic system does not permit a direct relation to the source of pollution. It is very likely that emergent macrophytes, rooted in sediments, are more adequate for

performing such evaluations. Effects of specific sources of contamination (organic or industrial) in lakes can be assessed by different concentrations of metals or nutrients in plant tissues.

S.californicus demonstrates some response to environmental changes regarding nutrients uptake and heavy metal concentrations. Transport of metals from sediments to stems, leaves and inflorescences appear to occur in emergent macrophytes in the littoral zone, indicating that such aquatic plants do play a role in heavy metal accumulations in the coastal lakes. The bulrush may represent a natural resource which could contribute to environmental evaluation as well as to lake characterization, depending on physical conditions and location of the littoral zone.

ZUSAMMENFASSUNG

Die aus der Kontamination aquatischer Systeme entstehenden Probleme zeigen die Notwendigkeit einer Auswertung von Nährstoffverfügbarkeit und Schwermetallkonzentrationen in aquatischen Makrophyten und Sedimenten in den natürlichen Systemen.

Obwohl viele Küstenseen in der Restinga von Rio Grande do Sul untersucht wurden, sind Studien über Biomasse und Nährstoffzusammensetzung der in dem Litoral südbrasilianischer Küstenseen lebenden emersen Makrophyten, selten.

Aus neun verschiedenen Seen (Palmital-, Caieira-, Peixoto-, Barros-, Emboaba-, Rincão das Éguas-, Porteira-, Barros-Solidão- und Tarumã- See) entlang der Küstenebene von Rio Grande do Sul und aus neun Randgebieten des Saco de Tapes (eine Bucht der Patos Lagune) wurden die Mineralstoffe und die Schwermetallkonzentrationen in den emersen Makrophyten und in den Sedimentprofile untersucht. Außer der Cyperaceae *Scirpus californicus* wurden die Macrophyten *Zizaniopsis bonariensis* (GRAMINEAE), *Cyperus giganteus* (CYPERACEAE), *Typha domingensis* (TYPHACEAE), *Echinodorus grandiflorus* (ALISMATACEAE) untersucht.

Das Ufer jedes Sees repräsentiert sehr verschiedenartig entwickelte Biotope, und das Verbreitungsmuster der Makrophyten spiegelt diese Dynamik wieder.

Veränderungen im Vertikalprofil von Phosphor, Stickstoff, Kalzium, Magnesium und Natrium zeigen, daß die Mineralstoffkonzentrationen der obersten Sedimentschichten mit den dynamischen Prozessen des Wassers zusammenhängen. Die chemischen Parameter innerhalb der Sedimentfolgen zeigen, daß die Uferzonen durch natürliche Prozesse unterschieden werden können,

wenn man die oberste und die unteren Sedimentschichten getrennt betrachtet.

In der Küstenebene zeigten der Caieira- und der Peixoto- See die höchsten Phosphorkonzentrationen im Sediment. Bis auf die Phosphorkonzentration hatte der Porteira-See nährstoffreichere Sedimente als die anderen Seen.

Die Mittelwerte der Nährstoffkonzentration in den Sedimenten der Uferbereiche der Seen der Küstenebene sind im Vergleich zu Angaben von tropischen Seen ausgesprochen gering.

In Küstennahen Ökosystemen spielt die Salinität des Wassers eine wichtige Rolle. Die Korrelation, die zwischen den Schwebstoffen und dem Chloridgehalt gefunden wurde, zeigt, daß die Ausfällung hauptsächlich am südlichen Rand vom der Saco de Tapes auftritt. Außerdem kann mit der Erhöhung des Salzgehaltes eine Konkurrenz zwischen Chloridionen und bei der Komplexbildung mit den gelösten Metallen auftreten.

Das Vorkommen von Schwermetallen in den Sedimentschichten der Uferbereiche der meisten Küstenseen spiegelt natürliche Prozesse wieder. In einigen wenigen Küstenseen (Emboaba- und Caieira- See) haben Immissionen eine gewisse Bedeutung.

Blei war das einzige Schwermetall, dessen durchschnittliche Konzentration in den Gesamtprofilsedimentproben und in deren oberen Schichten gleiche Werte hatte.

Zu- und Abnahme von Mineralstoffen in aquatischen Milieu sind durch das Gewebe von *S.californicus* und anderen in der Küstenebene vorkommenden emersen Makrophyten gut kontrollierbar. Von den untersuchten Mineralstoffen war Kalium der wichtigste und der am stärksten schwankende Nährstoff in der Pflanzenbiomasse.

Obwohl die Konzentration der Nährstoff in *S.californicus* von Standort zu Standort verschieden ist,

besteht nahezu eine vollkommene Übereinstimmung in der Relationen der einzelnen Nährstoffe verschiedener Pflanzen zueinander.

Die Einflüsse bestimmter Kontaminationsquellen auf die Seen, kann durch die unterschiedlichen Metallkonzentrationen im Pflanzengewebe bewertet werden. Die Blüten und Blätter der emersen Makrophyten zeigten höhere Schwermetallkonzentrationen als die Stengel.

Es bestehen auffallende Unterschiede des Schwermetallgehaltes in den verschiedenen Organen von *S.californicus*. Wenn man die Elementkonzentrationen zwischen Pflanzenproben von Uferzonen verschiedener Seen statistisch untersucht, stellt sich heraus, daß die Unterschiede zwischen den einzelnen Pflanzenorganen größer sind als diejenigen zwischen verschiedenen Individuen.

Die Entwicklung der Biomasse von *S.californicus* ist nicht durch den Nährstoffgehalt des Standortes begrenzt, denn es konnte keine Korrelation zwischen Biomasse und Nährstoffgehalt des Sedimentes festgestellt werden. Im Unterschied zur Vegetationsentwicklung in den gemäßigten Breiten, wo die Hauptentwicklung in den Sommermonaten stattfindet, wurden bei den Binsen an den Küstenseen der subtropischen Region zwei Höhepunkte der Mineralaufnahme und der Biomasseproduktion im Sommer und im Winter festgestellt.

S.californicus ist ein wichtiger Bioindikator, der zur Umweltbewertung und weiteren Charakterisierung von Seen beitragen könnte. Dabei müssen neben allgemeinen Kriterien wie z.B. die geographische Lage der Seen oder die Lage des Untersuchsgebietes, vor allem auch der Einfluß des Windes und der Sedimenttypen berücksichtigt werden.

RESUMO

Problemas advindos da crescente contaminaçao de sistemas aquáticos tornam necessárias medidas que visem avaliar a disponibilidade de nutrientes e as concentrações de metais pesados em macrófitas aquáticas e sedimentos em ambientes naturais.

Embora muitas lagoas costeiras tenham sido investigadas ao longo da Restinga do Rio Grande do Sul, estudos que enfoquem a avaliação da biomassa e a composição mineral de macrófitas emergentes são escassos.

As concentrações de minerais e de metais pesados foram investigadas em perfis sedimentológicos e em macrófitas emergentes de nove lagoas da Planície Costeira do Rio Grande do Sul (lagoas Palmital, Caieira, Peixoto, Barros, Emboaba, Rincão das Éguas, Porteira, Barros-Solidão e Tarumã), e em nove diferentes margens do Saco de Tapes (Laguna dos Patos). Juntamente à ciperácea *Scirpus californicus*, outras macrófitas emergentes como *Zizaniopsis bonariensis* (GRAMINEAE), *Cyperus giganteus* (CYPERACEAE), *Typha domingensis* (TYPHACEAE), e uma espécie eulitoral *Echinodorus grandiflorus* (ALISMATACEAE), foram analisadas.

A zona litoral dos lagos representa um biótopo altamente diferenciado, e os padrões apresentados pelas macrófitas emergentes refletem essa dinâmica.

Alterações nos perfis verticais de fósforo, nitrogênio, cálcio, magnésio e sódio têm demonstrado que as concentrações desses minerais no sedimento superficial encontram-se relacionadas a muitos fatores que refletem a dinâmica dos processos que ocorrem na água. As inter-relações dos parâmetros químicos ao longo do perfil sedimentológico, bem como na camada superficial, demonstram que os processos naturais, quando tratados separadamente, diferenciam a zona litoral dos lagos.

Na Planície Costeira, as lagoas Caieira e Peixoto apresentaram as mais elevadas concentrações de fósforo no sedimento. Dentre as lagoas estudadas, a Lagoa da Porteira apresentou, com exceção de fósforo, o sedimento mais rico em nutrients.

As médias das concentrações de nutrientes nos sedimentos da zona litoral dos lagos na Planície Costeira são extremamente baixas quando comparadas aos valores citados para algumas represas tropicais.

Em sistemas costeiros, a salinidade constitui um importante fator. A correlação observada entre o material em suspensão e a concentração de cloretos na água demonstra que uma precipitação ocorre principalmente na margen sul do Saco de Tapes. Além disso, com um aumento da salinidade, pode ocorrer uma competição entre os ions cloreto e particulados para uma complexação dos metais dissolvidos.

A distribuição de metais pesados em perfis sedimentológicos na zona litoral das lagoas costeiras reflete a ocorrência de processos naturais e, em algumas delas (como nas lagoas Emboaba e Caieira), fracos "inputs" atmosféricos.

Chumbo foi o único metal pesado cujos níveis não diferiram entre as análises efetuadas com o core total e aquelas considerando apenas a camada superficial do sedimento na zona litoral das lagoas costeiras.

A dinâmica dos nutrientes em ambientes aquáticos é especialmente detectada através da análise de tecidos de macrófitas como *S.californicus* e outras emergentes. Dentre os elementos minerais investigados, potássio demonstrou ser o mais importante e variável nutriente na biomassa.

Embora as concentrações de nutrientes no *S.californicus* diferem para cada local de coleta, existe uma quase perfeita correspondência entre os minerais

presentes, nas diferentes lagoas estudadas na Planície Costeira.

Assim como para os nutrientes, fontes específicas de contaminação de sistemas aquáticos podem ser avaliadas através da análise do conteúdo de metais nos diferentes órgãos das macrófitas emergentes. Dentre essas, rizomas, inflorescências e folhas apresentam as mais altas concentrações.

A análise estatística das concentrações de metais pesados em órgãos de *S.californicus*, nos diversos locais de coleta, evidenciaram que as variações entre as estruturas de uma mesma planta são maiores do que as variações individuais.

Nas lagoas estudadas, os juncos não estão limitados pelos nutrientes, uma vez que nenhuma correlação foi encontrada entre a concentração na biomassa e os minerais presentes no sedimento. Contrastando com plantas aquáticas de regiões temperadas, cuja biomassa máxima ocorre preponderantemente nos meses de verão, duas máximas de biomassa e assimilação de nutrientes são apresentadas pela espécie estudada: no verão e no inverno.

S.californicus, como um recurso natural, pode contribuir não somente na avaliação ambiental como também na caracterização dos sistemas aquáticos. Contudo, juntamente a critérios gerais como a situação geográfica da lagoa e localização da zona litoral, a ação dos ventos e o tipo de sedimento são fatores que devem ser levados em consideração.

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